

# Greenhouse Gas Emissions 1990-2021

## National Inventory Report



## Colophon

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## Preface

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 and entered into force in 1994. According to Articles 4 and 12 of the Convention, Parties are required to develop and submit to the UNFCCC national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol on an annual basis.

To comply with the above requirement, Norway has prepared the present 2023 National Inventory Report (NIR). The NIR and the associated Common Reporting Format (CRF) tables have been prepared in accordance with the revised UNFCCC Reporting Guidelines on Annual Inventories as adopted by the COP by its Decision 24/CP.19. The methodologies used in the calculation of emissions are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The structure of this report is consistent with the UNFCCC guidelines for inventory reporting.

The Norwegian Environment Agency, a directorate under the Norwegian Ministry of Climate and Environment, is responsible for the reporting. Statistics Norway has been the principal contributor while the Norwegian Institute of Bioeconomy Research is responsible for chapters 6 and all information regarding Land Use, Land Use Change and Forestry.

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## ES. Executive Summary

### ES1. Background information on greenhouse gas (GHG) inventories and climate change

The 1992 United Nations Framework Convention on Climate Change (UNFCCC) requires that the Parties to the Convention develop, update, and submit to the UNFCCC annual inventories of greenhouse gas emissions by sources and removals by sinks. This report documents the Norwegian National Inventory for the period 1990-2021.

The National Inventory Report (NIR) and the associated Common Reporting Format (CRF) tables have been prepared in accordance with the revised UNFCCC Reporting Guidelines on Annual Inventories as adopted by the COP by its Decision 24/CP.19. The methodologies used in the calculation of emissions are consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. As recommended by the IPCC Guidelines, country specific methods have been used where appropriate.

Emissions of the following greenhouse gases are covered in this report: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF<sub>6</sub>). Norway does not have any emissions of nitrogen trifluoride (NF<sub>3</sub>) to report. In addition, the inventory includes calculations of emissions of the precursors NO<sub>x</sub>, NMVOC, and CO, as well as SO<sub>2</sub>. Indirect CO<sub>2</sub> emissions originating from the fossil part of CH<sub>4</sub> and NMVOC are calculated and reported.

Aggregated emissions and removals of greenhouse gases expressed in CO<sub>2</sub> equivalents are also reported. We have used Global Warming Potentials (GWP) calculated on a 100-year time horizon, as provided by the IPCC in the Fifth Assessment Report. This is the first year Norway uses GWPs from the Fifth assessment report. This has led to significant recalculations of emissions compared to previous submissions.

### ES2. Summary of national emission and removal-related trends

In 2021, total greenhouse gas (GHG) emissions in Norway were 49.2 million tonnes of carbon dioxide equivalents, which is a decrease of 0.34 million tonnes compared to 2020. Emissions reached their peak at 56.7 million tonnes in 2007. They have since decreased by 13 percent, and were in 2021 2.2 million tonnes, or 4.2 percent, lower than in 1990. The emissions decreased by 4.2 % between 2019 and 2021.

The net GHG emissions, including all sources and sinks, were 33.7 million tonnes of CO<sub>2</sub> equivalents in 2021, a decrease of 18.8 % from 1990. This is due to an increase in carbon stored in living biomass, dead organic matter and in soils in Norway. The total net removal from the LULUCF sector was 15.5 million tonnes CO<sub>2</sub> equivalents in 2021. Forest land was the major contributor to the net sequestration of CO<sub>2</sub> in the sector. In 2021, the total net removals from forest land were 20.2 million tonnes of CO<sub>2</sub>.

In 2021, CO<sub>2</sub> contributed to 83.2 % of the total emission figures, while methane and nitrous oxide contributed to 10.7 % and 4.2 %, respectively. PFCs, HFCs and SF<sub>6</sub> together accounted for 1.9 % of the total GHG emissions.

### ES3. Overview of source and sink category emission estimates and trends

Figure ES0-1 shows the overall trend in the total emissions by gas for the period 1990-2021. The most important sector in Norway, with regards to the emissions of greenhouse gases (GHG), is the energy sector, accounting for 68.6 % of the total Norwegian emissions. The major sources of emissions within the energy sector are oil and gas extraction and transport.

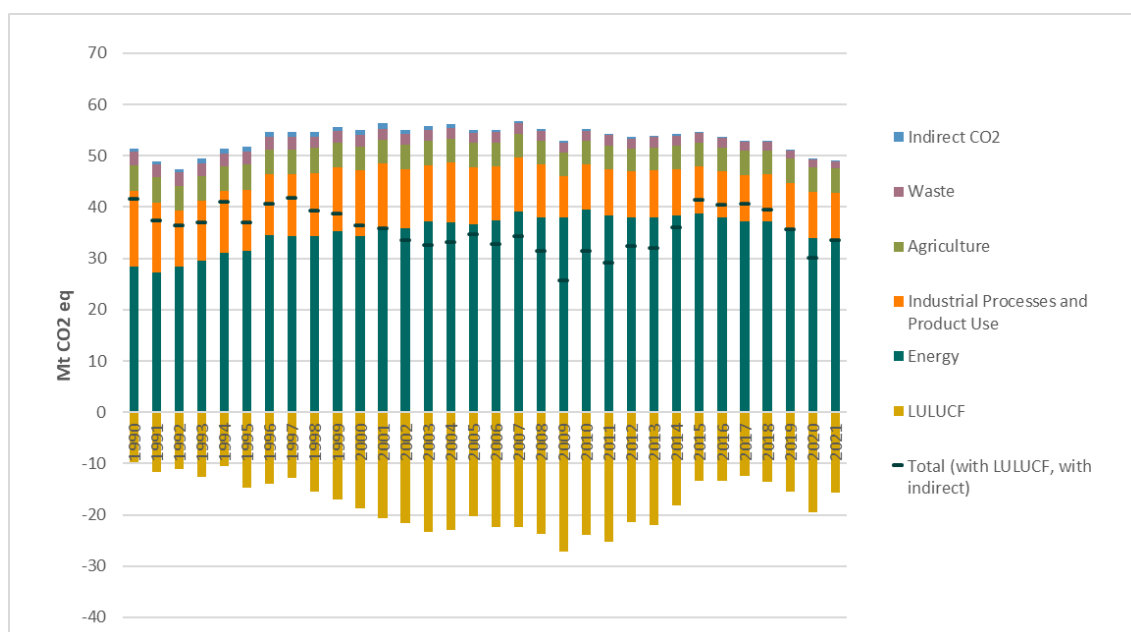


Figure ES0-1: Total emissions of greenhouse gases by sources, and removals from LULUCF in Norway, 1990-2021 (Mtonnes CO<sub>2</sub> equivalents).

Source: Statistics Norway/Norwegian Environment Agency/Norwegian Institute of Bioeconomy Research

Figure ES.3 shows the percentage change in emissions of greenhouse gases from 1990 to 2021 for the various IPCC sectors, compared to emissions in 1990. The development for each of the sectors since 1990 with regards to greenhouse gas emissions, and the most important sources, are described briefly in the following.

Norway has experienced economic growth since 1990. In addition, the offshore petroleum sector has expanded significantly. Together this has resulted in higher CO<sub>2</sub> emissions from energy use, both in energy industries and transport. Looking at the overall trend from 1990 to 2021, emissions from the energy sector increased by 19 %.

Emissions from transport showed an overall increase of 2.8 % from 1990 to 2021. The share of transport in the total GHG emissions has increased from 19.3 % in 1990 to 25.0 % in 2021. Road transportation accounted for 70.2 % of emissions from the transport sub-sector, while emissions from navigation and civil aviation accounted for 22.7 % and 6.7 %, respectively. Since most railways are electrified in Norway, emissions of GHG from this source are insignificant.

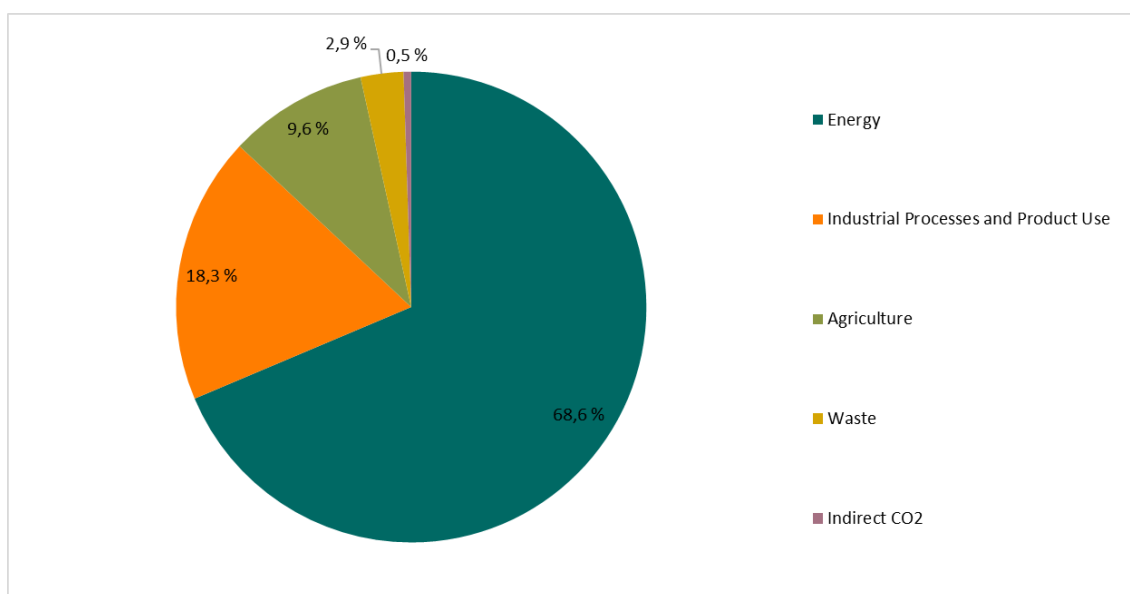
Industrial processes and other product use sector contributed to 18.6 % of the total national emissions of greenhouse gases in 2021. Production of metals and chemicals are the main sources of process-related industrial emissions of both CO<sub>2</sub> and other greenhouse gases such as N<sub>2</sub>O (fertilizer production) and PFCs (aluminium production). Between 1990 and 2021, emissions from industrial processes decreased by 38.3 %. This is mainly due to reduced PFC emissions from the production of aluminium and SF<sub>6</sub> from the production of magnesium.

The agricultural sector contributed in 2021 to 9.6 % of the total emissions of greenhouse gases, with its 4.7 million tonnes CO<sub>2</sub> equivalents. Emissions from agriculture decreased by 1.4 % between 2020 and 2021 and decreased by 5.0 % between 1990 and 2021. The dominant sources of GHGs are enteric fermentation (CH<sub>4</sub>) from domestic animals and agricultural soils (N<sub>2</sub>O). These sources contributed to about 54.5 % and 31.2 % to the sector's emissions, respectively.

The waste sector contributed to 2.9 % of total Norwegian greenhouse gas emissions in 2021. GHG emissions from the waste sector were relatively stable during the 1990s. From 1998, the emissions declined, and in 2021, they were 45.9 % lower than in 1990. Total waste volumes have increased significantly over the period, but this has been offset by increased recycling and incineration of waste as well as increased flaring of methane from landfills. Several measures introduced in the 1990s have resulted in smaller amounts of

waste disposed at disposal sites. With a few exceptions, it was then prohibited to dispose easy degradable organic waste at landfills in Norway. In 1999, a tax was introduced on waste delivered to final disposal sites. From July 1, 2009, it was banned to deposit biodegradable waste to landfills.

Figure ES2 shows the various IPCC sectors' share of the total greenhouse gas emissions in Norway in 2021.



*Figure ES0-2: Emissions by IPCC sector in 2021, excluding LULUCF.*

*Source: Statistics Norway/Norwegian Environment Agency*

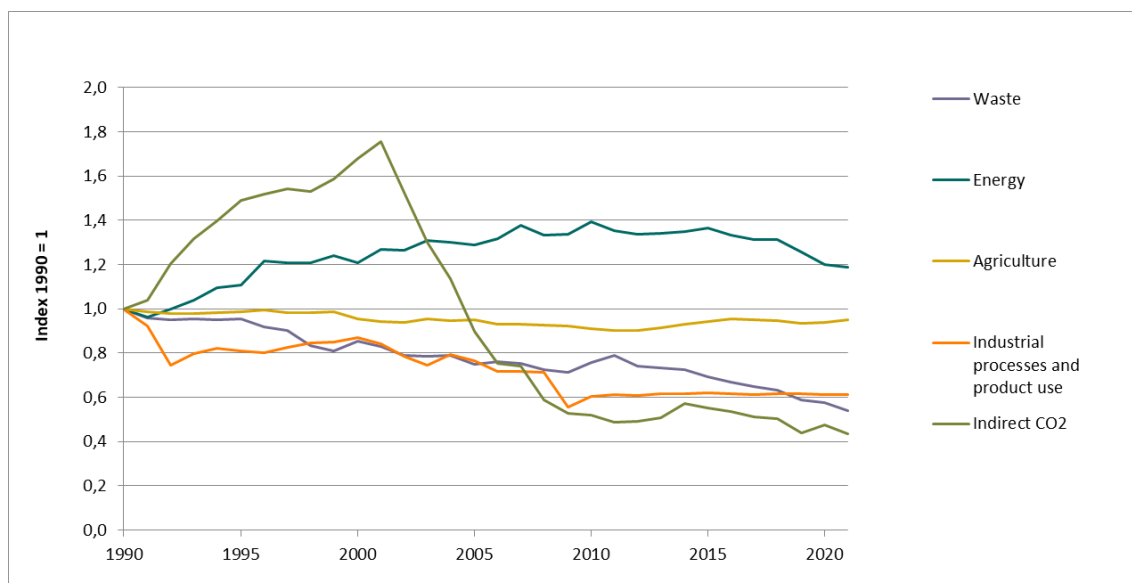


Figure ES0-3: Changes in GHG emissions relative to 1990, by IPCC sector 1990-2021. Index 1990=1.

Source: Statistics Norway/Norwegian Environment Agency

The proportion of CO<sub>2</sub> emissions of the national total greenhouse gas emissions has increased from about 68.3 % in 1990 to 83.2 % in 2021. The increased proportion of CO<sub>2</sub> relative to other gases is due to growth in the CO<sub>2</sub> emissions during this period, as well as a reduction in emissions of N<sub>2</sub>O, PFCs and SF<sub>6</sub> gases because of implemented environmental measures and/or technological improvements and closures of industrial plants.

| <b>Table ES-1 Emissions of greenhouse gases in Norway during the period 1990-2021.</b><br><b>Units: CO<sub>2</sub> in million tonnes (Mt), CH<sub>4</sub> and N<sub>2</sub>O in 1000 tonnes (kt) and other gases in 1000 tonnes CO<sub>2</sub> eq. (kt CO<sub>2</sub> eq.).</b> |                       |                       |                       |                             |                       |            |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------------|-----------------------|------------|
| <b>Gas</b>                                                                                                                                                                                                                                                                      | <b>CO<sub>2</sub></b> | <b>CH<sub>4</sub></b> | <b>N<sub>2</sub>O</b> | <b>PFC</b>                  | <b>SF<sub>6</sub></b> | <b>HFC</b> |
| <b>Year</b>                                                                                                                                                                                                                                                                     | <b>Mt</b>             | <b>kt</b>             |                       | <b>kt CO<sub>2</sub> eq</b> |                       |            |
| <b>1990</b>                                                                                                                                                                                                                                                                     | 35.0                  | 249.4                 | 13.8                  | 3499.8                      | 2163.0                | 0.0        |
| <b>1995</b>                                                                                                                                                                                                                                                                     | 38.5                  | 256.8                 | 12.4                  | 2078.9                      | 597.6                 | 91.9       |
| <b>2000</b>                                                                                                                                                                                                                                                                     | 42.1                  | 247.1                 | 12.8                  | 1364.1                      | 918.6                 | 356.7      |
| <b>2005</b>                                                                                                                                                                                                                                                                     | 43.3                  | 229.7                 | 13.6                  | 858.2                       | 306.0                 | 528.1      |
| <b>2010</b>                                                                                                                                                                                                                                                                     | 45.7                  | 223.1                 | 8.2                   | 214.3                       | 70.6                  | 855.4      |
| <b>2011</b>                                                                                                                                                                                                                                                                     | 44.8                  | 218.2                 | 8.2                   | 236.1                       | 55.3                  | 923.2      |
| <b>2012</b>                                                                                                                                                                                                                                                                     | 44.3                  | 214.4                 | 8.2                   | 180.3                       | 54.2                  | 979.9      |
| <b>2013</b>                                                                                                                                                                                                                                                                     | 44.6                  | 211.2                 | 8.2                   | 162.8                       | 57.1                  | 1068.1     |
| <b>2014</b>                                                                                                                                                                                                                                                                     | 45.0                  | 209.0                 | 8.2                   | 160.9                       | 50.3                  | 1028.1     |
| <b>2015</b>                                                                                                                                                                                                                                                                     | 45.5                  | 208.9                 | 8.3                   | 131.6                       | 69.7                  | 909.9      |
| <b>2016</b>                                                                                                                                                                                                                                                                     | 44.7                  | 205.4                 | 8.1                   | 167.4                       | 63.1                  | 950.7      |
| <b>2017</b>                                                                                                                                                                                                                                                                     | 44.1                  | 199.8                 | 8.0                   | 117.8                       | 58.0                  | 972.6      |
| <b>2018</b>                                                                                                                                                                                                                                                                     | 44.3                  | 196.6                 | 7.9                   | 133.1                       | 55.5                  | 939.7      |
| <b>2019</b>                                                                                                                                                                                                                                                                     | 42.7                  | 189.3                 | 8.0                   | 157.4                       | 70.1                  | 874.5      |
| <b>2020</b>                                                                                                                                                                                                                                                                     | 41.2                  | 188.9                 | 7.8                   | 145.2                       | 76.0                  | 749.8      |
| <b>2021</b>                                                                                                                                                                                                                                                                     | 40.9                  | 187.7                 | 7.8                   | 222.8                       | 62.5                  | 628.4      |

| <b>Table ES2 Emissions in million tonnes CO<sub>2</sub> equivalents in 1990, 2020, 2021, and changes (%) between 1990-2021 and 2020-2021 (without LULUCF).</b> |                       |                       |                       |             |                       |             |              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|-----------------------|-------------|-----------------------|-------------|--------------|
| <b>Year</b>                                                                                                                                                    | <b>CO<sub>2</sub></b> | <b>CH<sub>4</sub></b> | <b>N<sub>2</sub>O</b> | <b>PFCs</b> | <b>SF<sub>6</sub></b> | <b>HFCs</b> | <b>Total</b> |
| <b>1990</b>                                                                                                                                                    | 35.0                  | 7.0                   | 3.6                   | 3.5         | 2.2                   | 0.00005     | 51.3         |
| <b>2020</b>                                                                                                                                                    | 41.2                  | 5.3                   | 2.1                   | 0.1         | 0.1                   | 0.7         | 49.5         |
| <b>2021</b>                                                                                                                                                    | 40.9                  | 5.3                   | 2.1                   | 0.2         | 0.1                   | 0.6         | 49.2         |
| <b>Changes 1990-2021</b>                                                                                                                                       | 16.9 %                | -24.7 %               | -43.2 %               | -93.6 %     | -97.1 %               | 1286245.5 % | -4.2 %       |
| <b>Changes 2020-2021</b>                                                                                                                                       | -0.6 %                | -0.6 %                | 0.2 %                 | 53.5 %      | -17.8 %               | -16.2 %     | -0.7 %       |

Source: Statistics Norway/Norwegian Environment Agency

In 2021, 56.4 % of the methane emissions originated from agriculture, 20.1 % from the energy sector and 23.0 % from the waste sector. The total methane emissions decreased by 0.6 % from 2020 to 2021.

In 2021, agriculture contributed to 78.0 % of the total N<sub>2</sub>O emissions. The energy sector was the second biggest contributor, with 9.7 %. Industrial processes accounted for 9.2 % of the N<sub>2</sub>O emissions in 2021 (Almost entirely from fertilizer and nitric acid production), and the waste sector for 3.1 %. Due to technical improvements in production of nitric acid, and despite the increased production, the total emissions of N<sub>2</sub>O have decreased by 43.3 % since 1990.

The PFC emissions went up by 53.5 % from 2020 to 2021, however the emissions have, in total, been reduced by 93.6 % since 1990. In 2021, the only source of PFC emissions is aluminium production (perfluorocarbons tetrafluoromethane (CF<sub>4</sub>) and hexafluoroethane (C<sub>2</sub>F<sub>6</sub>)), where technical measures have been undertaken to reduce emissions. CO<sub>2</sub> emissions from aluminium production have increased since 1990 due to increased production levels. There were minor emissions of octafluoropropane (C<sub>3</sub>F<sub>8</sub>) from refrigeration in 2010-2014.

SF<sub>6</sub> emissions have been reduced by 97.1 % from 1990 to 2021, mainly because of technological improvements and the closure of a magnesium production plant and a magnesium recycling foundry.

Emissions of HFCs increased significantly from mid-1990s until they reached a peak around 2013. From 2020 to 2021 the emissions decreased by 16.2 %. Recent decline in emissions within industrial and transport refrigeration was mainly a consequence of restrictions from the F-gas regulation (implemented in Norway) which includes the restrictions to place on the market refrigeration equipment that contains HFCs with GWP of 2500 or more.

The net removal from the LULUCF sector was 15.5 million tonnes CO<sub>2</sub>-equivalents in 2021. Forest land is the land-use category responsible for the largest annual variations in CO<sub>2</sub> removals. The increase in living carbon stocks is result of an active forest management policy implemented over the last 60–70 years, which has led to an increase in the area of productive forest, as well as higher productivity in already existing forests. In addition, annual felling has been lower than annual increment. However, a large proportion of these forests are beginning to mature and hence reduce increment and leading to a future decline that is already apparent in the data. Croplands followed closely by settlements are the land-use categories that are responsible for the largest net emissions of the six land use categories in the LULUCF sector in 2021.

## ES4 Other information (precursors and SO<sub>2</sub>)

Nitrogen oxides (NO<sub>x</sub>), non-methane volatile organic compounds (NMVOC) and carbon monoxide (CO) are not greenhouse gases, but they have an indirect effect on the climate through their influence on greenhouse gases, in particular ozone. Sulphur dioxide (SO<sub>2</sub>) also has an indirect impact on climate, as it increases the level of aerosols with a subsequent cooling effect. Therefore, emissions of these gases are to some extent included in the inventory.

The overall NO<sub>x</sub> emissions have decreased by approximately 27.8 % from 1990 to 2021, primarily because of stricter emission regulations directed towards road traffic, which counteracted increased emissions from oil and gas production and from navigation. From 2020 to 2021, the total NO<sub>x</sub> emissions decreased by 3.5 %.

There was an increase in NMVOC emissions in the period from 1990 to 2001, mainly because of the rise in oil production and the loading and storage of oil. However, the emissions decreased by 65.6 % from 2001 to 2021 and were, in 2021, 55.2 % lower than in 1990. From 2020 to 2021, NMVOC emissions decreased by 3.7 %.

Over the period 1990-2021, emissions of CO decreased by 46.0 %. This is primarily explained by the implementation of new emissions standards for motor vehicles. Emissions of SO<sub>2</sub> were reduced by 70.2 % from 1990 to 2021. This can mainly be explained by a reduction in sulphur content of all oil products and lower process emissions from ferroalloys and aluminium productions, as well as refineries.



# 1. Introduction

## 1.1 Background information on GHG inventories and climate change

The 1992 United Nation Framework Convention on Climate Change (UNFCCC) was ratified by Norway on 9 July 1993 and entered into force on 21 March 1994. One of the commitments of the Convention is that Parties are required to report their national inventories of anthropogenic emissions by sources and removals by sinks of the greenhouse gases CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O as well as fluorinated greenhouse gases (HFCs, PFCs, NF<sub>3</sub> and SF<sub>6</sub>), using methodologies agreed upon by the Conference of the Parties to the Convention (COP).

In compliance with its reporting requirements, Norway has submitted to the UNFCCC national emission inventory reports on an annual basis since 1993. The National Inventory Report 2023 together with the associated Common Reporting Format (CRF) tables are Norway's contribution to the 2023 round of reporting and it covers emissions and removals for the period 1990-2021. Both the National Inventory Report and the CRF tables may be found on the UNFCCC web pages.

Previous NIRs have contained supplementary information required under Article 7, paragraph 1 of the Kyoto Protocol. For instance, see chapters 12-15 of the 2022 NIR. Most of this information is no longer reported, but Annex VI contains information related to Kyoto units, the national registry, and the Standard Electronic Format (SEF) table since the true up of the second commitment period of the Kyoto Protocol still has to take place. The national inventory report is prepared in accordance with the revised UNFCCC Reporting Guidelines on Annual Inventories as adopted by the COP by its Decision 24/CP.19. The methodologies used in the calculation of emissions and removals are consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. As recommended by the IPCC Guidelines, country specific methods have been used where appropriate and where they provide more accurate emission data.

The greenhouse gases or groups of gases included in the national inventory are the following:

- Carbon dioxide (CO<sub>2</sub>)
- Methane (CH<sub>4</sub>)

- Nitrous oxide (N<sub>2</sub>O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF<sub>6</sub>)

Norway has examined whether there are activities that would result in emissions of trinitrogenfluoride (NF<sub>3</sub>), and our assessment is that there are no emissions of NF<sub>3</sub> in Norway.

Aggregated emissions and removals of greenhouse gases expressed in CO<sub>2</sub> equivalents are also reported. We have used Global Warming Potentials (GWP) calculated on a 100-year time horizon, as provided by the IPCC in the Fifth Assessment Report.

Indirect CO<sub>2</sub> emissions originating from the fossil part of CH<sub>4</sub> and NMVOC are calculated according to the reporting guidelines to the UNFCCC and are included in the inventory. This includes emissions from fuel combustion and non-combustion sources, such as fugitive emissions from loading of crude oil, oil refineries, distribution of oil products, and from solvents and other product use. See more in chapter 9.

The report also contains calculations of emissions of the precursors and indirect greenhouse gases NO<sub>x</sub>, NMVOC, CO and SO<sub>2</sub>, which should be included according to the reporting guidelines. However, we have in this submission not included detailed descriptions of the calculation methodologies for these gases. This information is available in Norway's annual report to the Convention on Long-range Transboundary Air Pollution.

Since the introduction of annual technical reviews of the national inventories by independent experts in 2000, Norway has undergone desk/centralized/in-country reviews. The recommendations from these reviews have resulted in many improvements to the inventory. For the latest implemented improvements and planned improvements, see chapter 10.

## 1.2 A description of the national inventory arrangements

### 1.2.1 Institutional, legal, and procedural arrangements

The Norwegian CO<sub>2</sub> emission inventory has been produced for more than three decades and was gradually expanded with other emission components. It started as a collaboration between Statistics Norway and the Norwegian Environment Agency, and the reporting to

the UNFCCC has evolved based on this greenhouse gas emission inventory. The institutions in the national greenhouse gas inventory system in Norway are the Norwegian Environment Agency, Statistics Norway, and the Norwegian Institute of Bioeconomy Research (NIBIO). Statistics Norway is responsible for the calculation of emissions from the Energy, Industrial Processes and Product Use (IPPU), Agriculture and Waste source categories. The Norwegian Institute of Bioeconomy Research is responsible for the calculations of emission and removals from Land Use, Land-Use Change and Forestry (LULUCF).

The Norwegian Environment Agency was appointed as the national entity through budget propositions to the Norwegian parliament for 2006 and 2015 (Prop. 1S (2014-2015)). These propositions describe the institutional arrangements (National System) and still apply.

To ensure that the institutions comply with their responsibilities, Statistics Norway and the Norwegian Institute of Bioeconomy Research have signed agreements with Norwegian Environment Agency as the national entity. Through these agreements, the institutions are committed to implementing the QA/QC and archiving procedures, providing documentation, making information available for review, and delivering data and information in a timely manner to meet the deadline for reporting to the UNFCCC.

### **1.2.2 Overview of inventory planning, preparation, and management**

The Norwegian Environment Agency, Statistics Norway, and the Norwegian Institute of Bioeconomy Research are the institutions of the national greenhouse gas inventory system and work together to fulfill the requirements for the national system.

The allocation of responsibilities for producing estimates of emissions and removals, QA/QC and archiving is presented in more detail in section 1.2.3, section 1.3, and Annex V. An overview of institutional responsibilities and cooperation is shown in Figure 1-1.

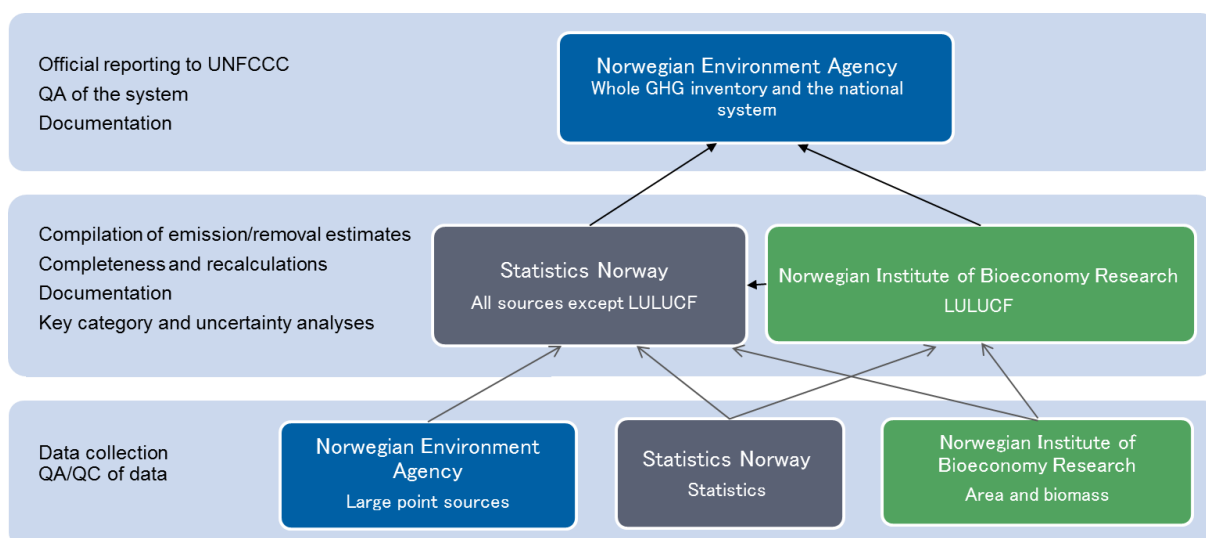


Figure 1-1 Overview of institutional responsibilities and cooperation

### 1.2.3 Quality assurance, quality control and verification

#### 1.2.3.1 Quality assurance and quality control (QA/QC)

Several quality assurance and quality control procedures for the preparation of the national emission inventory have been established in Norway during the past years. Statistics Norway made its first emission inventory for some gases in 1983 for the calculation year 1973. The emission estimation methodologies and the QA/QC procedures have been developed continuously since then.

Norway has implemented a formal quality assurance/quality control plan. The detailed description of this is found in Annex V. All three institutions annually prepare a QA/QC report, according to the plan. These reports document to what extent the QA/QC procedures have been followed. These reports are available to the UNFCCC expert review teams.

Based on these reports, the three institutions collaborate to decide on which actions to take to further improve the QA/QC of the inventory.

This chapter describes general QA/QC procedures. For source specific QA/QC, see each source sector for detailed descriptions. The QA/QC work has several dimensions, of which accuracy and timeliness are the most essential. As these two aspects may be in conflict, the QA/QC improvements in recent years have focused on how to implement an effective

QA/QC procedure and how to obtain a more efficient dataflow in the inventory system. Transparency is also an important issue that steadily receives more attention.

The established QA/QC procedures include the following:

- The Norwegian Environment Agency is the national entity designated to be responsible for the reporting of the national inventory of greenhouse gases to the UNFCCC. This includes coordination of the QA/QC procedures.
- Statistics Norway and the Norwegian Institute of Bioeconomy Research are responsible for the quality control system regarding technical activities of the emission inventory preparation in their respective institutions.
- General inventory level QC procedures, as listed in table 6.1 in chapter 6, volume 1, of the 2006 IPCC Guidelines (IPCC 2006) are performed every year.
- Source category-specific QC procedures are performed for key categories and some non-key categories with regard to emission factors, activity data and uncertainty estimates.

### **1.2.3.2 QA Procedures**

According to the IPCC Good practice guidance, good practice for QA procedures requires an objective review to assess the quality of the inventory and to identify areas where improvements should be made. Furthermore, it is good practice to use QA reviewers that have not been involved in preparing the inventory. In Norway, the Norwegian Environment Agency is responsible for reviewing the inventory with regard to quality and areas for improvement.

Norway has performed several studies comparing inventories from different countries (Kvingedal et al. 2000). Annex V gives more information concerning the quality assurance of emission data in the Norwegian emission inventory.

### **1.2.3.3 General QC procedures**

The Norwegian emission inventory is produced in several steps. Statistics with preliminary emission estimates are published by Statistics Norway in June the year after the inventory year. These data are based on preliminary statistics and indicators and data that have been subjected to a less thorough quality control. The more final emission statistics, which forms the basis for the emission inventory reported to the UNFCCC (for all source categories except LULUCF) is published in November the year after the inventory year. At this stage, final statistics are available for almost all emission sources. Recalculations of the inventory are performed annually to ensure that methodological changes and refinements are implemented for the whole time series. This stepwise procedure is a part of the QA/QC procedure since all differences in data are recorded and verified.

General quality control procedures are performed for each of the steps above, but with different levels of detail and thoroughness as mentioned. The national emission model was revised in 2002 to facilitate the QC of the input data rather than the emission data only. Input data include emissions reported from large plants, activity data, emission factors and other estimation parameters.

In the following, the procedures listed in table 6.1 in chapter 6 of the 2006 IPCC Guidelines (IPCC 2006) are described, as well as how these checks are performed for the Norwegian greenhouse gas emission inventory.

#### 1.2.3.3.1 Check that assumptions and criteria for the selection of activity data, emissions factors, and other estimation parameters are documented

Thorough checks of emission factors and activity data and their documentation are performed for existing emission sources. When new sources appear (for example a new industrial plant) or existing sources for the first time are recognised as a source, the Norwegian Environment Agency delivers all relevant information to Statistics Norway. This information is then thoroughly checked by the inventory team at Statistics Norway. All changes in methodologies or data are documented and kept up to date.

#### 1.2.3.3.2 Check for transcription errors in data input and references

Activity data are often statistical data. Official statistical data undergo a systematic revision process, which may be manual or computerised. The revision significantly reduces the number of errors in the statistics used as input to the inventory. Furthermore, all input data (reported emissions, emission factors and activity data) for the latest inventory year are routinely compared to those of the previous inventory year, using automated procedures. Large changes are automatically flagged for further, manual QC. In addition, implied emission factors (IEFs) are calculated for emissions from stationary combustion at point sources. The IEFs are subjected to the same comparison between the years  $t$  and  $t-1$ . The most thorough checks are made for the gases and categories with the largest contribution to total emissions.

#### 1.2.3.3.3 Check that emissions and removals are calculated correctly

When possible, estimates based on different methodologies are compared. An important example is the metal production sector, where CO<sub>2</sub> estimates reported by the plants are compared with estimates based on the Good Practice methodology corrected for national circumstances. In this case, both production-based and reducing agent-based calculations are performed to verify the reported value. The Norwegian Environment Agency and Statistics Norway control and verify emission data reported to the Norwegian Environment Agency by industrial enterprises, registered in the database Forurensning. First, the

Norwegian Environment Agency checks the data received from these plants, and if errors are discovered, they may then ask the plants responsible to submit new data.

Subsequently, Statistics Norway makes, where possible, occasional comparable emission calculations based on activity data sampled in official statistics, and deviations are explained through contact with the plants. Regarding more detailed information about the QC of data reported by industrial plants, see Annex V and VIII.

#### 1.2.3.3.4 Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used

All parameter values are compared with values used in previous years and with any preliminary figures available. Whenever large deviations are detected, the value of the parameter in question is first checked for typing errors or unit errors. Changes in emissions from large plants are compared with changes in activity level. If necessary, the primary data suppliers (e.g., the Norwegian Institute of Bioeconomy Research, The Norwegian Petroleum Directorate, Norwegian Public Roads Administration, various plants etc.) are contacted for explanations and possible corrections.

#### 1.2.3.3.5 Check the integrity of database files

Control checks of whether appropriate data processing steps and data relationships are correctly represented are made for each step of the process. Furthermore, it is verified that data fields are properly labelled, have correct design specifications and that adequate documentation of database and model structure and operation are archived.

#### 1.2.3.3.6 Check for consistency in data between source categories

Activity data and other parameters that are common to several source categories should be evaluated for consistency. An example is recovery of landfill gas. A fraction of this gas is flared, and emissions are reported in the Waste source category. Another fraction is recovered for energy purposes, and this gas is an input to the energy balance with emissions reported in the Energy source category. Consistency checks ensure that the amount landfill gas subtracted from source category 5A (Managed waste disposal on land), equals the amount added to source category 1A (Energy combustion) and source category 5C (Waste incineration) (the amount of gas flared).

Consistency is also checked for activity data that is used in both the Agriculture and LULUCF sectors. This is the case for the area of organic soils on croplands and grasslands, which is used to estimate CO<sub>2</sub> emissions in the LULUCF sector (source categories 4.B and 4.C) and N<sub>2</sub>O emissions in the agriculture sector (source category 3D16). Within agriculture

(source categories 3A, 3B and 3D), the same activity data on animal numbers and characteristics is used as far as possible.

**1.2.3.3.7 Check that the movement for inventory data among processing steps is correct**  
Statistics Norway has established automated procedures to check that inventory data fed into the model does not deviate too much from the estimates for earlier years, and that the calculations within the model are correctly made. Checks are also made that emissions data are correctly transcribed between different intermediate products. The model is constructed so that it gives error messages if factors are lacking, which makes it quite robust to miscalculations.

**1.2.3.3.8 Check that uncertainties in emissions and removals are estimated and calculated correctly**

An approach 2 uncertainty analysis for greenhouse gases is undertaken annually, see further information in section 1.6.2 and Annex II.

**1.2.3.3.9 Undertake review of internal documentation**

For some sources, expert judgements dating some years back are used for activity data/emission factors. In most of the cases these judgements have not been reviewed since, and may not be properly documented, which may be a weakness of the inventory. The procedures have improved the last few years, and the requirements for internal documentation to support estimates are now quite strict; all expert judgements and assumptions made by the Statistics Norway staff should be documented. This should increase reproducibility of emissions and uncertainty estimates.

**1.2.3.3.10 Check of changes due to recalculations**

Emission time series are recalculated every year to ensure time series consistency. The recalculated emission data for a year are compared with the corresponding estimates from the year before. For example, CO<sub>2</sub> data calculated for 1990 in 2021 are compared with the 1990 CO<sub>2</sub> data calculated in 2020. The intention is to explain all major differences as far as possible. Changes may be due to revisions in energy data, new plants, correction of former errors and new emission methodologies.

**1.2.3.3.11 Undertake completeness checks**

Estimates are reported for all source categories and for all years to the best of our knowledge except for a few known data gaps, which are listed in section 1.7. There may, of course, exist sources of greenhouse gases which are not covered. However, emissions from potentially additional sources are likely to be very small or negligible. During the implementation of the 2006 IPCC Guidelines (IPCC 2006), a systematic evaluation of all potential new sources was performed.



#### 1.2.3.3.12 Compare estimates to previous estimates

Internal checks of time series for all emission sources are performed every year when an emission calculation for a new year is implemented. It is examined whether any detected inconsistencies are due to data and/or methodology changes. For example, in 2017 Statistics Norway/the Norwegian Environment Agency calculated emission data for 2016 for the first time. These data were compared with the 2015 estimates for detection of any considerable deviations. There may be large deviations that are correct, caused for instance by the shutdown of large industrial plants or the launch of new ones.

#### 1.2.3.4 Source category-specific QC procedures

Statistics Norway and the Norwegian Environment Agency have carried out several studies on specific emission sources, e.g., emissions from road, sea, and air transport, emissions from landfills as well as emissions of HFCs and SF<sub>6</sub>. These projects are repeated in regular intervals when new information is available. During the studies, emission factors have been assessed and amended to represent the best estimates for national circumstances, and a rationale for the choice of emission factor is provided. The emission factors are often compared with factors from literature. Furthermore, activity data have been closely examined and quality controlled, as have the uncertainty estimates.

The QC procedures for the different emission sources are described in the QA/QC-chapters of the relevant source-categories. The source category-specific analyses have primarily been performed for key categories on a case-by-case basis, which is described as good practice. The QC procedures are described Annex V and Annex VII.

#### 1.2.3.5 Verification studies

In general, the final inventory data provided by Statistics Norway and the Norwegian Institute of Bioeconomy Research are checked and verified by Norwegian Environment Agency. Some verification studies, which have been performed previously, are briefly described in the following.

Emission estimates for a source are often compared with estimates performed with a different methodology. In particular, Norway has conducted a study on verification of the Norwegian emission inventory (Kvingedal et al. 2000). The main goals of that work were to investigate the possibility of using statistical data as indicators for comparing emission estimates between countries on a general basis, and to test the method on the Norwegian national emission estimates. In the report, Norwegian emission data were compared with national data for Canada, Sweden, and New Zealand. It was concluded that no large errors in the Norwegian emission inventory were detected. The process of verification did,

however, reveal several smaller reporting errors; emissions that had been reported in other categories than they should have been. These errors were corrected. We acknowledge that this method of verification only considers consistency and completeness compared with what other countries report. It is not a verification of the scientific value of the inventory data themselves.

In 2002, a project funded by the Nordic Council of Ministers compared emissions of greenhouse gases from the agricultural sector in the national emission inventories with the emissions derived from the IPCC default methodology and the IPCC default factors. In 2006, as part of the improvements for the Initial report under the Kyoto Protocol, the Norwegian Environment Agency performed a major QA/QC exercise on the time series from 1990 to 2004 of greenhouse gas (GHG) emissions from the largest industrial plants in Norway. A first time series of emission data as well as activity data was established for each plant based on existing data sources. It was then possible to identify lack of emission data and activity data for any year or time series and possible errors in the reported data.

Possible errors were typically identified if there were discrepancies between reported activity data (consumption of raw materials, production volumes etc.) and emissions, or if there were large variations in the existing time series of emissions. The emission data were supplemented and/or corrected, if possible, by supply of new data from the company, supplementary data from Norwegian Environment Agency paper archives, verification of reported emission data by new calculations based on reported activity data and calculation of missing emissions (if sufficient activity data were present). A final time series of greenhouse gas emissions from 1990 to 2004 were established and the main documentation from this work is contained in Excel spread sheets and in a documentation report (SFT 2006). This approach is described in Annex VII.

From 2005 and especially from 2008, Norway's use of plant specific data has been strengthened by the availability of data from the EU ETS. The Norwegian Environment Agency conducted the verification of the annual reports up until the inventory year 2012. Since then, verification has been performed by an accredited third party. As a data source, the EU ETS provides better quality data, and these data are checked against the emissions reported under the regular permits and the reports submitted as part of the voluntary agreement. More details are found in Annex VII.

In 2009, a new model for calculating the emissions of NMVOC from the use of solvents and other product uses was developed. The emission factors were evaluated and revised through a cooperation project between the Nordic countries. The results from the new

model were compared against the similar results in Sweden and the United Kingdom; see Holmengen and Kittilsen (2009) for more details.

In 2011, the Norwegian University of Life Sciences (NMBU) published a comparison of the methodologies used for calculating CH<sub>4</sub> emissions from manure management in Sweden, Finland, Denmark and Norway (Morken & Hoem 2011).

In a project in 2012 at the Norwegian University of Life Sciences (NMBU) that updated the Norwegian nitrogen excretion factors and the values for manure excreted for different animal species, comparisons were made with the corresponding factors used in Sweden, Denmark and Finland and with IPCC default factors as a verification of the Norwegian factors (Karlengen et al. 2012). Comparisons were also made of the emission factors used for calculating enteric methane. In 2015, the equations for calculating emissions from enteric fermentation were evaluated and updated.

In 2015, IEFs for many of the IPPU source categories have been compared with what other Annex I countries have reported using a tool developed by the UNFCCC.<sup>1</sup>

In 2019, a technical committee on agricultural greenhouse gas emission ("Teknisk beregningsutvalg for klimagassutslipp i jordbruk") on behalf of the Ministry of Agriculture and Food, published its final report<sup>2</sup>. This document pointed out possible ways to improve the emission inventory to better reflect mitigation measures and where enhanced knowledge is needed.

The Norwegian Government and the agricultural organisations have in 2019 entered a letter of intent about reducing greenhouse gas emissions and increase the carbon sink from agriculture with 5 million tonnes CO<sub>2</sub> equivalents for the period 2021-2030. As part of the follow-up of this deal will the recommendations from the Technical committee on agricultural greenhouse gas emission be followed up on a yearly basis, and other possible improvements will be pointed out which can contribute to the knowledge base for improvements of activity data or emission factors in the national emission inventory.

#### **1.2.3.6 Confidentiality issues**

In general, the data contained in the Norwegian emission inventory are available to the public, both emission estimates, activity data and emission factors. Data that are confidential according to the Statistics Act are replaced by non-confidential data collected

<sup>1</sup> [http://unfccc.int/ghg\\_data/ghg\\_data\\_unfccc/items/4146.php](http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php)

<sup>2</sup> [https://www.regjeringen.no/contentassets/0f1af0ca7efe493e8e48b46b6fba5ffd/rapport-tbu-jordbruk\\_siste.pdf](https://www.regjeringen.no/contentassets/0f1af0ca7efe493e8e48b46b6fba5ffd/rapport-tbu-jordbruk_siste.pdf)

by the Norwegian Environment Agency for most sources. Confidentiality is still an issue for some of the data collected by Statistics Norway when there are few entities reporting for a source category. To comply with confidentiality issues, emission estimates for these sources are aggregated. This is especially prominent in source category 2F, where emissions from 2F2-5 are aggregated in category 2F6 due to confidentiality.

#### **1.2.3.7 Quality assurance and quality control (QA/QC) and verification for the LULUCF sector**

The Norwegian Institute of Bioeconomy Research (NIBIO) implements the QA/QC plan described for the National Greenhouse Gas Inventory System in Annex V. A LULUCF-specific plan for QA/QC was developed internally at NIBIO. The LULUCF-specific plan has two objectives: 1) to ensure that emission estimates and data contributing to the inventory are of high quality, and 2) to facilitate an assessment of the inventory in terms of quality and completeness. These objectives are in accordance with chapter 6 of the 2006 IPCC guidelines (IPCC 2006) for quality assurance and quality control.

The QA/QC plan for the LULUCF sector is based on the general Tier 1 QC procedures and includes two check lists (one for the source-category compiler and one for the LULUCF inventory compiler), an annual timeframe of the outlined QC activities, and a target for when to elicit QA reviews. In general, QA is initiated if a new method or model is implemented.

Internal structures at NIBIO have changed slightly every year with regard to the LULUCF reporting. Existing QC procedures are evaluated and improved upon each year to ensure that the methods and calculations used are subjected to an internal QC prior to reporting. The CRF tables go through internal QC by more than one person before the database is submitted to the national focal point. Furthermore, after the overall compilation of estimates from all sectors, there is an exchange of CRF tables from the focal point to NIBIO, and an additional QC is performed. Improving the QA/QC procedures is an ongoing process that will be further improved in future submissions.

#### **1.2.4 Changes in the national inventory arrangements since previous submission**

There have been no changes to the national inventory arrangements since the previous submission.

### 1.3 Inventory preparation, data collection, processing, and storage

The institutions in the national inventory system; the Norwegian Environment Agency, Statistics Norway, and the Norwegian Institute of Bioeconomy Research, have agreed on a “milestone” production plan. This production plan reflects national publishing obligations etc. The plan is described in Annex V (Norway’s National System) and is supplemented by internal production plans in each of the three institutions.

The three institutions of the national system have defined areas of responsibility for data collection, this is further described in Annex V.

Statistics Norway is responsible for the collection and development of activity data and compiling of the data used in the models that produce emission estimates for the source categories Energy, IPPU, Agriculture and Waste. Statistics Norway also operates these models. The Norwegian Environment Agency is responsible for the emission factors, for providing data from specific industries and sources and for considering the quality, and assuring necessary updating, of emissions models like e.g., the road traffic model and calculation of methane emissions from landfills. Emission data are used for a range of national applications and for international reporting.

The Norwegian Institute of Bioeconomy Research is responsible for the estimated emissions from the LULUCF sectors, collects almost all data and calculates the emissions.

The collected data are subjected to the Quality Assessment and Quality Control (QA/QC) routines described in section 1.2.3 and Annex V, as well as source specific routines as described under each source chapter. They are all (except data regarding LULUCF) subsequently processed by Statistics Norway into a format appropriate to enter the emission models. The models are designed in a manner that accommodates both the estimation methodologies reflecting Norwegian conditions and those recommended internationally.

All three institutions are responsible for archiving the data they collect and the estimates they calculate with associated methodology documentation and internal documentation on QA/QC. Due to the differences in the character of data collected, Norway has chosen to keep archiving systems in the three institutions, which means that not all information is archived at a single location. These archiving systems are, however, consistent, and operate under the same rules. Although the data are archived separately, all can be

accessed efficiently during a review. In addition, the Norwegian Environment Agency has established a library with the most important methodology reports.

## 1.4 Brief general description of methodologies (including tiers used) and data sources used

### 1.4.1 Introduction

Norway has an integrated inventory system for producing inventories of the greenhouse gases included in the Kyoto Protocol, as well as the air pollutants SO<sub>2</sub>, NO<sub>x</sub>, non-methane volatile organic compounds (NMVOC), ammonia, CO, particulate matter, heavy metals, and persistent organic pollutants reported under the LRTAP Convention. The data flow and QA/QC procedures are to a large extent common to all pollutants.

The emission estimation methodologies are being improved continuously. Statistics Norway and the Norwegian Environment Agency have carried out several studies on specific emission sources. Often, such projects are connected to an evaluation of emission reduction measures. An important consequence of Statistics Norway's work is increased environmental relevance of the statistical system. As far as possible, data collection relevant to the emission inventories is integrated into other surveys and statistics.

### 1.4.2 The main emission model

The model was developed by Statistics Norway (Daasvatn et al. 1992; 1994). It was redesigned in 2003 to improve reporting to the UNFCCC and LRTAP, and to improve QA/QC procedures.

Several emission sources – e.g., road traffic, agriculture, air traffic and solvents – are covered by more detailed side models. Aggregated results from these side models are used as input to the general model.

The general emission model is based on the following equation:

$$\text{Emissions (E)} = \text{Activity level (A)} \times \text{Emission Factor (EF)}$$

For emissions from *combustion*, the activity data is use of energy products. In the Norwegian energy accounts, the use of energy products is allocated to industries

(economic sectors). To calculate emissions to air, energy use must also be allocated to technical sources (e.g., equipment). This makes it possible to match activity data with relevant emission factors.

The energy use data are combined with a corresponding matrix of emission factors. In principle, there should be one emission factor for each combination of fuel, industry, source, and pollutant. However, in a matrix with a cell for each combination, most of the cells would be empty (no consumption), while on the other hand, the same emission factor would apply to many cells.

Emissions of some pollutants from major manufacturing plants (point sources) are available from measurements or other plant-specific calculations (collected by the Norwegian Environment Agency). When such measured data are available, they are normally considered to give better representation of the actual emission, and the estimated values are replaced by the measured ones:

$$Emissions (E) = [(A - A_{PS}) \times EF] + E_{PS}$$

where  $A_{PS}$  and  $E_{PS}$  are the activity and the measured emissions at the point sources, respectively. Emissions from activities for which no point source estimate is available ( $A - A_{PS}$ ) are still estimated with the standard emission factor.

*Non-combustion* emissions are generally calculated in the same way, by combining appropriate activity data with emission factors. Some emissions are measured directly and reported to the Norwegian Environment Agency from the plants, and some may be obtained from current reports and investigations. The emissions are fitted into the general model using the parameters industry, technical source, and pollutant. The fuel parameter is not relevant here. The source sector categories are based on EMEP/NFR and UNFCCC/CRF categories, with further subdivisions where more detailed methods are available.

The model uses approximately 220 industries (economic sectors). The classification is common with the basis data in the energy balance/accounts, and is almost identical to that used in the national accounts, which is aggregated from the European NACE classification (Statistics Norway 2008). The large number of sectors is an advantage in dealing with important emissions from manufacturing industries. The disadvantage is an unnecessary disaggregation of sectors with very small emissions. To make the standard sectors more appropriate for calculation of emissions, a few changes have been made, e.g., "Private households" is defined as a sector.

### 1.4.3 The LULUCF model

The Norwegian Institute of Bioeconomy Research is responsible for estimating emissions and removals from Land use, Land-Use Change and Forestry (LULUCF), where most of the categories have area statistics as activity data. A software-based calculation system that primarily uses the statistical software R for data processing and analysis, was developed for the implementation of the IPCC good practice guidance for the LULUCF sector. The system uses input data from different sources and creates final output datasets. These final datasets include all the data needed for the tables reported to the Climate Convention and the Paris Agreement.

The National Forest Inventory (NFI) database contains data on areas for all land uses and land-use conversions as well as carbon stocks in living biomass. The NFI is used to estimate total areas of forest land, cropland, grassland, wetlands, settlements, other land, and land-use transitions between these categories. The data from the NFI are complemented with other data (e.g., timber harvest, horticulture, crop types, fertilizer use, and forest fires) collected by Statistics Norway, Norwegian Agricultural Authority, The Norwegian Food Safety Authority, The Norwegian Environment Agency, The Directorate for Civil Protection, and FAO forestry statistics.

The sampling design of the NFI is based on a systematic grid of geo-referenced sample plots covering the entire country. The NFI utilizes a 5-year cycle based on a re-sampling method of the permanent plots (interpenetrating panel design). Up until 2010 the estimates were based on detailed information from sample plots in lowlands outside Finnmark county. Since 2010 the NFI has been expanded to include mountainous areas and Finnmark county, to monitor the land use, land-use changes, and forestry activities in the whole country. All areas were included for the first time in the estimates for the LULUCF sector in the 2012 submission. Area estimates have been bridged in a consistent manner.

The estimates of carbon stocks and their changes in living biomass are based on single tree measurements of trees larger than 50 mm at 1.3 m height (DBH) on sample plots within forest and other wooded land. Biomass is calculated using single tree allometric biomass models developed in Sweden for Norway spruce and Scots pine (Marklund 1988; Petersson & Ståhl 2006) and Norwegian models for birch (Smith 2016; Smith 2014). These models provide biomass estimates for various tree biomass components: stem, bark, living branches, dead branches, foliage, stumps, and roots. These components are used to calculate above- and belowground biomass.



The dynamic soil model Yasso07 is used to calculate changes in carbon stock in dead organic matter and in the mineral soil for forest land remaining forest land (Tuomi et al. 2009; 2011b). Estimates are made for individual NFI plots for the entire time-series. The Yasso07 model provides an aggregated estimate of carbon stock change for the total of litter, dead wood, and soil organic matter. All data used as input to the models is provided by the NFI. Auxiliary data used for estimation of C emissions from cropland, grassland, wetlands, and settlements were provided by Statistics Norway, Norwegian Meteorological Institute, as well as other data sources at the Norwegian Institute of Bioeconomy Research.

#### 1.4.4 Data sources

The data sources used in the Norwegian inventory are outlined in the following.

*Activity levels:* These normally originate from official statistical sources available internally in Statistics Norway and other material available from external sources. When such information is not available, research reports are used, or extrapolations are made from expert judgments.

*Emission factors:* These originate from reports on Norwegian conditions and are either estimated from measurements or elaborated in special investigations. However, international default data are used in cases where national emission factors are highly uncertain or lacking (e.g., N<sub>2</sub>O from agriculture, CH<sub>4</sub> and N<sub>2</sub>O from stationary combustion) or when the source is insignificant in relation to other sources.

*Aggregated results from the side models:* The operation of the side models in the inventory requires various sets of additional parameters pertinent to the emission source at hand. These data sets are as far as possible defined in official registers, public statistics, and surveys, but some are based on assumptions.

*Emission figures for point sources:* For large industrial plants these are figures reported to the Norwegian Environment Agency by the plants' responsible (based on measurements or calculations at the plants).

### 1.5 Brief description of key categories

According to the IPCC definition, key categories are those that add up to 90% of the total uncertainty in level and/or trend. In the Norwegian greenhouse gas emission inventory key categories are primarily identified by means of an Approach 2 method. A description of the

methodology as well as background tables and the result from the analyses is presented in Annex 1. In this chapter a summary of the analysis and the results are described.

According to the IPCC Good Practice Guidance (IPCC 2006) it is good practice to give the results at the Approach 2 level if available. The advantage of using an Approach 2 methodology is that uncertainties are taken into account and the ranking shows where uncertainties can be reduced. However, in the 2006 IPCC guidelines it is suggested that good practice reporting should include key categories from both Approach 1 and Approach 2.

The Approach 2 and Approach 1 analyses were performed at the level of IPCC source categories and each greenhouse gas from each source category was considered separately with respect to total GWP weighted emissions, except land-use, land-use change and forestry (LULUCF).

The results from the key category analyses are summarized in [Table 1.1](#) (excluding LULUCF). In addition, we have also included a category identified on qualitative criteria. Altogether there are 48 key categories. Key categories in LULUCF were identified in separate analyses and are summarized in [Table 1.2](#).

The complete analyses are included in Annex I together with background data and the complete analysis including LULUCF.

The Approach 1 analysis included in the NIR uses a different aggregation level for some source categories than in the Approach 1 analysis generated in the CRF reporter. For the 2023 submission the analyses are based on AR5 CO<sub>2</sub> equivalent values for emissions. The trend assessment approach 1 is updated according to the 2019 refinements, equation 4.2.

As a QAQC of this implementation the previous and the updated trend assessments were performed on the same data and the key outputs were compared. There were no changes in the level approach 1 and 2 assessments, and only changes in the ranks of keys for the trend assessments.

| <b>Table 1.1 Summary of identified emission key categories. Excluding LULUCF.</b> |                                                   |                  |                                      |    |    |    |          |
|-----------------------------------------------------------------------------------|---------------------------------------------------|------------------|--------------------------------------|----|----|----|----------|
| IPCC Category Code                                                                | IPCC Category                                     | Green-house gas  | Identification criteria <sup>1</sup> |    |    |    | Method   |
| 1A1,1A2,1A4                                                                       | Stationary combustion, Solid Fuels                | CO <sub>2</sub>  | L1                                   | T1 | L2 |    | Tier 2   |
| 1A1,1A2,1A4                                                                       | Stationary combustion, Biomass                    | CH <sub>4</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1A1,1A2,1A4                                                                       | Stationary combustion, Gaseous Fuels              | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1A1,1A2,1A4                                                                       | Stationary combustion, Gaseous Fuels              | CH <sub>4</sub>  |                                      |    | L2 | T2 | Tier 2   |
| 1A1,1A2,1A4                                                                       | Stationary combustion, Liquid Fuels               | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1A1,1A2,1A4                                                                       | Stationary combustion, Other Fuels                | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1A3a                                                                              | Civil Aviation                                    | CO <sub>2</sub>  | L1                                   | T1 | L2 |    | Tier 3   |
| 1A3b                                                                              | Road Transportation                               | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
|                                                                                   |                                                   |                  |                                      |    |    |    |          |
| 1A3d                                                                              | Navigation                                        | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1A3d                                                                              | Navigation                                        | CH <sub>4</sub>  |                                      | T1 | L2 | T2 | Tier 2   |
| 1A4                                                                               | Other Sectors, mobile combustion                  | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1A5b                                                                              | Mobile                                            | CO <sub>2</sub>  | L1                                   | T1 |    | T2 | Tier 2   |
| 1B1a                                                                              | Coal Mining                                       | CH <sub>4</sub>  | L1                                   | T1 | L2 | T2 | Tier 1   |
| 1B2a                                                                              | Oil (incl. oil refineries, gasoline distribution) | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1B2a                                                                              | Oil (incl. oil refineries, gasoline distribution) | CH <sub>4</sub>  | L1                                   | T1 | L2 | T2 | Tier 2   |
| 1B2b                                                                              | Natural Gas                                       | CH <sub>4</sub>  |                                      |    |    | T2 | Tier 2   |
| 1B2c                                                                              | Venting and Flaring                               | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 3   |
| 1B2c                                                                              | Venting and Flaring                               | CH <sub>4</sub>  | L1                                   | T1 | L2 | T2 | Tier 3   |
| 2A1                                                                               | Cement Production                                 | CO <sub>2</sub>  | L1                                   |    |    |    | Tier 3   |
| 2A2                                                                               | Lime Production                                   | CO <sub>2</sub>  | L1                                   | T1 |    |    | Tier 3   |
| 2B1                                                                               | Ammonia Production                                | CO <sub>2</sub>  | L1                                   | T1 | L2 |    | Tier 2   |
| 2B2                                                                               | Nitric Acid Production                            | N <sub>2</sub> O | L1                                   | T1 | L2 | T2 | Tier 3   |
| 2B5                                                                               | Carbide Production                                | CO <sub>2</sub>  | L1                                   | T1 |    | T2 | Tier 2   |
| 2B6                                                                               | Titanium dioxide production                       | CO <sub>2</sub>  | L1                                   |    |    |    | Tier 2   |
| 2B8                                                                               | Petrochemical and carbon black production         | CO <sub>2</sub>  | L1                                   | T1 | L2 |    | Tier 2   |
| 2C2                                                                               | Ferroalloys production                            | CO <sub>2</sub>  | L1                                   | T1 | L2 |    | Tier 2/3 |
| 2C3                                                                               | Aluminium production                              | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 2/3 |
| 2C3                                                                               | Aluminium production                              | PFCs             | L1                                   | T1 | L2 | T2 | Tier 2   |
| 2C4                                                                               | Magnesium production                              | SF <sub>6</sub>  | L1                                   |    |    |    | Tier 2   |
| 2D1                                                                               | Lubricant use                                     | CO <sub>2</sub>  |                                      | T1 |    |    | Tier 2   |

|      |                                                                                   |                  |    |    |    |    |           |
|------|-----------------------------------------------------------------------------------|------------------|----|----|----|----|-----------|
| 2D3  | Solvent use, road paving and other <sup>2</sup>                                   | CO <sub>2</sub>  | L1 |    |    |    | Tier 1/ 2 |
| 2F   | Product uses as substitutes for ODS                                               | HFCs             | L1 | T1 | L2 | T2 | Tier 2    |
| 2H2  | Food and beverages industry                                                       | CO <sub>2</sub>  |    | T1 |    |    | Tier 2    |
| 3A1  | Enteric Fermentation- Cattle                                                      | CH <sub>4</sub>  | L1 | T1 | L2 |    | Tier 2    |
| 3A2  | Enteric Fermentation -Sheep                                                       | CH <sub>4</sub>  | L1 |    | L2 |    | Tier 2    |
| 3A4  | Other                                                                             | CH <sub>4</sub>  | L1 |    | L2 |    |           |
| 3B1  | Manure management – Cattle                                                        | CH <sub>4</sub>  | L1 |    | L2 |    | Tier 2    |
| 3B   | Manure Management                                                                 | N <sub>2</sub> O |    |    | L2 |    | Tier 2    |
| 3Da1 | Direct emissions from managed soils -Inorganic N fertilizers                      | N <sub>2</sub> O | L1 |    | L2 |    | Tier 1    |
| 3Da2 | Direct emissions from managed soils – Organic N fertilizer                        | N <sub>2</sub> O | L1 |    | L2 | T2 | Tier 1    |
| 3Da3 | Direct emissions from managed soils – Urine and dung deposited by grazing animals | N <sub>2</sub> O | L1 |    | L2 |    | Tier 1    |
| 3Da4 | Direct emissions from managed soils – Crop residues                               | N <sub>2</sub> O |    |    | L2 |    | Tier 1    |
| 3Da6 | Direct emissions from managed soils – Cultivation of organic soils                | N <sub>2</sub> O | L1 |    | L2 |    | Tier 1    |
| 3Db1 | Indirect emissions from managed soils – Atmospheric deposition                    | N <sub>2</sub> O |    |    | L2 |    | Tier 1    |
| 3Db2 | Indirect emissions from managed soils – Nitrogen leaching and run-off             | N <sub>2</sub> O |    |    | L2 |    | Tier 1    |
| 3G   | Liming                                                                            | CO <sub>2</sub>  | L1 | T1 |    |    | Tier 1    |
| 5A1a | Managed Waste Disposal sites. Anaerobic.                                          | CH <sub>4</sub>  | L1 | T1 | L2 | T2 | Tier 2    |
| 5B   | Biological treatment of Solid Waste                                               | CH <sub>4</sub>  |    |    |    | T2 | Tier 1    |
| 5D1  | Domestic wastewater treatment and discharge                                       | CH <sub>4</sub>  | L1 |    | L2 |    | Tier 1    |

<sup>1</sup> "L" refers to level and "T" to trend analyses. Numbers refer to approaches. "Q" refers to qualitative criteria.

<sup>2</sup> The 2D3 category covers 2D3a Solvent use, 2D3b Road paving and asphalt and 2D3d Other (use of urea).

The Approach 1 level analysis (excluding LULUCF) for 2021 identified one new source: CH<sub>4</sub> from coal mining.

The Approach 1 trend analysis identifies two new sources: CO<sub>2</sub> from Civil aviation (1A3a) and CH<sub>4</sub> from Navigation (1A3d).

The Approach 2 level analysis identified five new sources: CO<sub>2</sub> from Stationary combustion Solid Fuels (1A1-4) and Ammonia Production (2B1), CH<sub>4</sub> Manure management – Cattle (3B1) and Managed Waste Disposal sites, anaerobic, and N<sub>2</sub>O from Manure management (3B).

The Approach 2 trend analyses identified two new sources: CO<sub>2</sub> from Mobile (1A5b) and CH<sub>4</sub> from Managed Waste Disposal sites. Anaerobic.

Two sources are no longer key categories: CH<sub>4</sub> from Industrial wastewaters (5D2) and N<sub>2</sub>O from Domestic wastewater treatment and discharge (5D1) did not qualify in the level and trend approaches.

For LULUCF 41 key categories were identified by Approach 2 level and trend assessments. 13 categories were added and 1 key category was removed.

| Table 1.2 Summary of identified LULUCF key categories. |                                                                    |                  |                                      |    |    |    |            |
|--------------------------------------------------------|--------------------------------------------------------------------|------------------|--------------------------------------|----|----|----|------------|
| IPCC Category Code                                     | IPCC Category                                                      | Green-house gas  | Identification criteria <sup>1</sup> |    |    |    | Method     |
| 4(II)Crop                                              | Cropland - drained organic soil - Organic soil CC + LC             | CH <sub>4</sub>  |                                      |    | L2 |    | Tier 1     |
| 4(II)Forest                                            | Forest land drained organic soils - Drained organic soil           | N <sub>2</sub> O |                                      |    | L2 |    | Tier 1     |
| 4A1                                                    | Forest remaining forest - Litter + dead wood + Mineral soil        | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 3     |
| 4A1                                                    | Forest remaining forest - Living biomass                           | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 3     |
| 4A1                                                    | Forest remaining forest, drained organic soils - Organic soil      | CO <sub>2</sub>  | L1                                   |    | L2 |    | Tier 1     |
| 4A21                                                   | Cropland to Forest – DW                                            | CO <sub>2</sub>  |                                      |    | L2 |    | Tier 1     |
| 4A21                                                   | Cropland to Forest - Living biomass                                | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1 & 3 |
| 4A21                                                   | Cropland to Forest - Litter                                        | CO <sub>2</sub>  |                                      |    | L2 |    | Tier 1     |
| 4A22ex                                                 | Extensive Grassland to Forest - DW                                 | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1     |
| 4A22ex                                                 | Extensive Grassland to Forest -Litter                              | CO <sub>2</sub>  |                                      | T1 | L2 | T2 | Tier 1     |
| 4A22in                                                 | Intensive Grassland to Forest - DW                                 | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1     |
| 4A22in                                                 | Intensive Grassland to Forest - Living biomass                     | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1 & 3 |
| 4A22in                                                 | Intensive Grassland to Forest - Litter                             | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1     |
| 4A23u                                                  | Unmanaged Wetland to Forest -DW                                    | CO <sub>2</sub>  |                                      |    | L2 |    | Tier 1     |
| 4A23u                                                  | Unmanaged Wetland to Forest - Living biomass                       | CO <sub>2</sub>  |                                      |    |    | T2 | Tier 3     |
| 4A23u                                                  | Unmanaged Wetland to Forest - Litter                               |                  |                                      |    | L2 | T2 | Tier 1     |
| 4A24                                                   | Settlements to Forest – DOM                                        | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1     |
| 4A24                                                   | Settlements to Forest – Litter                                     | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1     |
| 4B1                                                    | Cropland remaining cropland - Organic soil                         | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 1     |
| 4B21                                                   | Forest to Cropland – DOM                                           | CO <sub>2</sub>  |                                      | T1 | L2 | T2 | Tier 1     |
| 4B21                                                   | Forest to Cropland - Living biomass                                | CO <sub>2</sub>  |                                      |    | L2 | T2 | Tier 1 & 3 |
| 4B21                                                   | Forest to Cropland - Organic soil                                  | CO <sub>2</sub>  |                                      |    | L2 |    | Tier 1     |
| 4B23u                                                  | Unmanaged Wetland to Cropland - Organic soil                       | CO <sub>2</sub>  |                                      | T1 | L2 | T2 | Tier 1     |
| 4C1ex                                                  | Extensive Grassland remaining extensive grassland – Living biomass | CO <sub>2</sub>  | L1                                   |    |    |    | Tier 2     |
| 4C1in                                                  | Intensive Grassland remaining intensive grassland - Living biomass | CO <sub>2</sub>  |                                      |    | L2 |    | Tier 2     |
| 4C1in                                                  | Intensive Grassland remaining intensive grassland – Mineral soil   | CO <sub>2</sub>  |                                      |    |    | T2 | Tier 1     |
| 4C1in                                                  | Intensive Grassland remaining intensive grassland –Organic soil    | CO <sub>2</sub>  |                                      |    | L2 |    | Tier 1     |
| 4C21in                                                 | Forest to Intensive Grassland – DOM                                | CO <sub>2</sub>  | L1                                   | T1 | L2 | T2 | Tier 1     |

|        |                                                            |                 |    |    |    |    |            |
|--------|------------------------------------------------------------|-----------------|----|----|----|----|------------|
| 4C21in | Forest to Intensive Grassland - Living biomass             | CO <sub>2</sub> |    | T1 | L2 | T2 | Tier 1 & 3 |
| 4D11   | Wetland Peat extraction - Organic soil                     | CO <sub>2</sub> |    |    | L2 |    | Tier 2     |
| 4D13m  | Managed Wetlands remaining managed wetlands - Organic soil | CO <sub>2</sub> |    |    | L2 |    | Tier 1     |
| 4D23m  | Forest to Managed Wetland -DOM                             | CO <sub>2</sub> |    |    | L2 |    | Tier 1     |
| 4D23m  | Forest to Managed Wetland -Living biomass                  | CO <sub>2</sub> |    |    | L2 |    | Tier 3     |
| 4E11   | Settlements remaining settlements - Organic soil           | CO <sub>2</sub> |    | T1 | L2 | T2 | Tier 1     |
| 4E211  | Forest to Settlement – DOM                                 | CO <sub>2</sub> | L1 |    | L2 | T2 | Tier 1     |
| 4E211  | Forest to Settlement - Living biomass                      | CO <sub>2</sub> | L1 |    | L2 | T2 | Tier 1 & 3 |
| 4E211  | Forest to Settlement - Mineral soil                        | CO <sub>2</sub> |    |    | L2 | T2 | Tier 1     |
| 4E211  | Forest to Settlement - Organic soil                        | CO <sub>2</sub> |    |    | L2 |    | Tier 1     |
| 4E221  | Cropland to Settlement -Mineral soil                       | CO <sub>2</sub> |    |    | L2 | T2 | Tier 1     |
| 4E221  | Cropland to Settlement - Organic soil                      | CO <sub>2</sub> |    |    | L2 |    | Tier 1     |
| 4E241u | Unmanaged Wetland to settlements - Organic soil            | CO <sub>2</sub> |    |    |    | T2 | Tier 1     |
| 4G     | Harvested wood Products – HWP                              | CO <sub>2</sub> |    | T1 | L2 | T2 | Tier 2     |

<sup>1</sup> "L" refers to level and "T" to trend analyses. Numbers refer to approaches.

## 1.6 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

### 1.6.1 Approach 1 uncertainty analysis

The uncertainties in the emission levels for 2021 have been investigated by an approach 1 analysis. The results are given in [Table 1.3](#) and [Table 1.4](#). For the 2023 submission the uncertainty analyses are based on AR5 CO<sub>2</sub> equivalents emission values.

| Table 1.3 Approach 1 uncertainties in emission levels. |                   |                            |
|--------------------------------------------------------|-------------------|----------------------------|
| 2021                                                   | m (mean)          | Uncertainty 2s (% of mean) |
| Total                                                  | 49.2 mill. tonnes | 3                          |
| CO <sub>2</sub>                                        | 40.9 mill. tonnes | 3                          |
| CH <sub>4</sub>                                        | 5.3 mill. tonnes  | 11                         |
| N <sub>2</sub> O                                       | 2.1 mill. tonnes  | 35                         |
| HFC                                                    | 628ktonnes        | 53                         |
| PFC                                                    | 223 ktonnes       | 21                         |
| SF <sub>6</sub>                                        | 62 ktonnes        | 44                         |

| <b>Table 1.4 Approach 1 uncertainties in emission levels.</b> |                   |                            |
|---------------------------------------------------------------|-------------------|----------------------------|
| 2021                                                          | m (mean)          | Uncertainty 2s (% of mean) |
| Total                                                         | 33.7 mill. tonnes | 14                         |
| <b>CO<sub>2</sub></b>                                         | 25.0 mill. tonnes | 18                         |
| <b>CH<sub>4</sub></b>                                         | 5.5 mill. tonnes  | 11                         |
| <b>N<sub>2</sub>O</b>                                         | 2.3 mill. tonnes  | 33                         |
| HFC                                                           | 628 ktonnes       | 53                         |
| PFC                                                           | 223 ktonnes       | 21                         |
| SF <sub>6</sub>                                               | 62 ktonnes        | 44                         |

### 1.6.2 Approach 2 uncertainty analysis

The uncertainty in the Norwegian greenhouse gas emission inventory has been investigated by an approach 2 analysis and the results are given in [Table 1.5](#) to [Table 1.8](#). The approach 2 analysis is also further described in Annex II.

The uncertainty in the Norwegian emission inventory was initially investigated systematically in three reports (Kvingedal et al. 2000; Rypdal 1999; Rypdal & Zhang 2001). The first two reports focused on the uncertainty in the greenhouse gas emissions, based on approach 2 analyses, and the last report investigated the uncertainty in the emission estimates of long-range air pollutants. The analysis of greenhouse gases was repeated in Statistics Norway (2010a) and more thoroughly in (Flugsrud & Hoem 2011). The report *Uncertainties in the Norwegian Greenhouse Gas Emission Inventory* (Rypdal & Zhang 2000) includes more detailed documentation of the analysis method used in all analyses. Both approach 1 and 2 uncertainty analyses are now performed annually.

The national greenhouse gas (GHG) emission inventory is compiled from estimates based on emission factors and activity data and direct measurements by plants. All these data and parameters will contribute to the overall inventory uncertainty. The uncertainties and probability distributions of the inventory input parameters have been assessed based on available data and expert judgements. Finally, the level and trend uncertainties of the national GHG emission inventory have been estimated using Monte Carlo simulation. The methods used in the analysis correspond to an IPCC Approach 2 method, as described in the IPCC guidelines (IPCC 2006). Analyses have been made both excluding and including the sector LULUCF (Land Use, Land-Use Change and Forestry).



Table 6.2 from the IPCC good practice guidance is included in Annex II as Table AII-4. Column G in table 6.2 is estimated as uncertainty for source category divided by total GHG emissions.

For the 2023 submission the uncertainty analyses are based on AR5 CO<sub>2</sub> equivalents emission values.

### 1.6.2.1 Uncertainty in emission levels

The estimated uncertainties of the levels of total emissions and in each gas are shown in Table 1.5 and Table 1.6.

| <b>Table 1.5 Uncertainties in emission levels.<br/>Each gas and total GWP weighted emissions. Excluding the LULUCF sector.</b> |                   |                             |                            |
|--------------------------------------------------------------------------------------------------------------------------------|-------------------|-----------------------------|----------------------------|
| 1990                                                                                                                           | m (mean)          | Fraction of total emissions | Uncertainty 2s (% of mean) |
| Total                                                                                                                          | 51.3 mill. tonnes | 1                           | 3                          |
| <b>CO<sub>2</sub></b>                                                                                                          | 35.0 mill. tonnes | 0.68                        | 3                          |
| <b>CH<sub>4</sub></b>                                                                                                          | 7.0 mill. tonnes  | 0.14                        | 8                          |
| <b>N<sub>2</sub>O</b>                                                                                                          | 3.6 mill. tonnes  | 0.07                        | 26                         |
| HFC                                                                                                                            | 49 tonnes         | 0.00                        | 51                         |
| PFC                                                                                                                            | 3.5 mill. tonnes  | 0.07                        | 20                         |
| SF <sub>6</sub>                                                                                                                | 2.2 mill. tonnes  | 0.04                        | 2                          |
| 2021                                                                                                                           | m (mean)          | Fraction of total emissions | Uncertainty 2s (% of mean) |
| Total                                                                                                                          | 49.2 mill. tonnes | 1                           | 3                          |
| <b>CO<sub>2</sub></b>                                                                                                          | 40.9 mill. tonnes | 0.83                        | 3                          |
| <b>CH<sub>4</sub></b>                                                                                                          | 5.3 mill. tonnes  | 0.11                        | 9                          |
| <b>N<sub>2</sub>O</b>                                                                                                          | 2.1 mill. tonnes  | 0.04                        | 47                         |
| HFC                                                                                                                            | 628.4 ktonnes     | 0.01                        | 51                         |
| PFC                                                                                                                            | 222.8 ktonnes     | 0.00                        | 20                         |
| SF <sub>6</sub>                                                                                                                | 62.5 ktonnes      | 0.00                        | 42                         |

| <b>Table 1.6 Uncertainties in emission levels.<br/>Each gas and total GWP weighted emissions. Including the LULUCF sector.</b> |                   |                             |                            |
|--------------------------------------------------------------------------------------------------------------------------------|-------------------|-----------------------------|----------------------------|
| 1990                                                                                                                           | m (mean)          | Fraction of total emissions | Uncertainty 2s (% of mean) |
| Total                                                                                                                          | 41.5 mill. tonnes | 1                           | 11                         |
| <b>CO<sub>2</sub></b>                                                                                                          | 24.8mill. tonnes  | 0.60                        | 18                         |
| <b>CH<sub>4</sub></b>                                                                                                          | 7.2 mill. tonnes  | 0.17                        | 8                          |
| <b>N<sub>2</sub>O</b>                                                                                                          | 3.9 mill. tonnes  | 0.09                        | 25                         |
| HFC                                                                                                                            | 44 tonnes         | 0.00                        | 51                         |
| PFC                                                                                                                            | 3.9 mill. tonnes  | 0.08                        | 20                         |
| SF <sub>6</sub>                                                                                                                | 2.1 mill. tonnes  | 0.05                        | 1                          |
| 2021                                                                                                                           | m (mean)          | Fraction of total emissions | Uncertainty 2s (% of mean) |
| Total                                                                                                                          | 33.7 mill. tonnes | 1                           | 15                         |
| <b>CO<sub>2</sub></b>                                                                                                          | 25.0 mill. tonnes | 0.74                        | 20                         |
| <b>CH<sub>4</sub></b>                                                                                                          | 5.5 mill. tonnes  | 0.16                        | 9                          |
| <b>N<sub>2</sub>O</b>                                                                                                          | 2.3 mill. tonnes  | 0.07                        | 41                         |
| HFC                                                                                                                            | 628.4 ktonnes     | 0.02                        | 51                         |
| PFC                                                                                                                            | 222.8 ktonnes     | 0.01                        | 20                         |
| SF <sub>6</sub>                                                                                                                | 62.5 ktonnes      | 0.00                        | 42                         |

The total national emissions of GHG (LULUCF sector excluded) in 1990 are estimated with an uncertainty of 3% of the mean. The main emission component CO<sub>2</sub> is known with an uncertainty of 3% of the mean. The total uncertainty level was 3% of the mean in 2021.

There have been major changes in uncertainty level for the different emission components between the two years. The highest uncertainty change between 1990 and 2021 is in the uncertainty estimates for the SF<sub>6</sub> emissions, which has increased from 1 to 42% of the mean. However, the SF<sub>6</sub> emissions are strongly reduced because magnesium production was closed. The figures for the emission of SF<sub>6</sub> from magnesium production was quite well known, but now a larger part of the SF<sub>6</sub> emissions comes from sources with higher uncertainty. For N<sub>2</sub>O there is also a considerable increase in the uncertainty between the years. One reason for the change can be found in that N<sub>2</sub>O from the production of synthetic fertilizer with a quite low uncertainty contributes to a smaller part of the total N<sub>2</sub>O emissions in 2021 than in 1990. For the other gases there are only smaller changes in the uncertainty from 1990 to 2021.

By including the LULUCF sector the results from the analysis show a total uncertainty of 11% of the mean in 1990 and 15% in 2021. This is because the uncertainty in the LULUCF sector in general is higher than in most other sectors.

### 1.6.2.2 Uncertainty in emission trend

The estimated uncertainties of the trends of total emissions and each gas are shown in Table 1.7 and Table 1.8.

| <b>Table 1.7 Uncertainty of emission trends. 1990-2021.<br/>Excluding the LULUCF sector.</b> |                                                 |                                  |
|----------------------------------------------------------------------------------------------|-------------------------------------------------|----------------------------------|
|                                                                                              | % change $((m_{2021}-m_{1990}) * 100/m_{1990})$ | Uncertainty $(2*s*100/m_{1990})$ |
| Total                                                                                        | -4                                              | 3                                |
| CO <sub>2</sub>                                                                              | 17                                              | 3                                |
| CH <sub>4</sub>                                                                              | -25                                             | 4                                |
| N <sub>2</sub> O                                                                             | -43                                             | 4                                |
| HFC <sup>1</sup>                                                                             | ..                                              | ..                               |
| PFC                                                                                          | -94                                             | 19                               |
| SF <sub>6</sub>                                                                              | -97                                             | 1                                |

| <b>Table 1.8 Uncertainty of emission trends. 1990-2021.<br/>Including the LULUCF sector.</b> |                                               |                                  |
|----------------------------------------------------------------------------------------------|-----------------------------------------------|----------------------------------|
|                                                                                              | % change $((m_{2021}-m_{1990})*100/m_{1990})$ | Uncertainty $(2*s*100/m_{1990})$ |
| Total                                                                                        | -19                                           | 6                                |
| CO <sub>2</sub>                                                                              | 1                                             | 9                                |
| CH <sub>4</sub>                                                                              | -24                                           | 4                                |
| N <sub>2</sub> O                                                                             | -40                                           | 4                                |
| HFC <sup>1</sup>                                                                             | ..                                            | ..                               |
| PFC                                                                                          | -94                                           | 19                               |
| SF <sub>6</sub>                                                                              | -97                                           | 1                                |

<sup>1</sup> The base year emissions of HFCs are so close to zero that figures for % change and uncertainty are meaningless.

The result shows that the decrease in the total GHG emissions from 1990 to 2021 is 4%, with an uncertainty in the trend of  $\pm 3$  percentage points, when the LULUCF sector is not included. This means that the 2021 emissions are likely between 0 and 6% below the 1990 emissions (a 95 percent confidence interval).

With the sector LULUCF included in the calculations there has been a decrease in the total emissions figures on -19%, with a trend uncertainty of  $\pm 6$  percentage points.

## 1.7 General assessment of completeness

An assessment of the completeness of the emission inventory should, according to the IPCC Good Practice Guidance, address the issues of spatial, temporal, and sectoral coverage along with all underlying source categories and activities. Confidentiality is an additional element of relevance, which has been addressed in section 1.2.3.6.

The inventory includes emissions on the archipelago Svalbard as well as on mainland Norway. In particular, emissions from coal mining on Svalbard is included.

The revised UNFCCC Reporting Guidelines on Annual Inventories as adopted by the COP by its Decision 24/CP.19 specifies that a Party may consider that a disproportionate amount of effort would be required to collect data for a gas from a specific category that would be insignificant in terms of the overall level and trend in national emissions and in such cases use the notation key NE. The Party should in the NIR provide justifications for exclusion in terms of the likely level of emissions. An emission should only be considered insignificant if the likely level of emissions is below 0.05% of the national total GHG emissions (specified in a footnote to total GHG emissions without LULUCF for the latest reported inventory year) and does not exceed 500 kt CO<sub>2</sub> equivalents. The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1% of the national total GHG emissions.

Norway has used the emissions for 2021 as reported in this NIR as the basis for national total GHG emissions. The national total GHG emissions without LULUCF in 2021 is reported to be 49 158 818 tonnes CO<sub>2</sub> equivalents. The threshold for an individual emission to be considered insignificant is therefore 24 579 tonnes CO<sub>2</sub> equivalents while the total threshold to be considered insignificant is 49 159 tonnes CO<sub>2</sub> equivalents.

The emissions (excluding LULUCF) that Norway has considered as insignificant, and their likely level of emissions are presented in [Table 1.9](#). The individual emissions excluded are all below the individual threshold and the total emissions excluded are also below the total threshold. [Table 1.10](#) provides information on emissions reported as NE for the LULUCF-sector.

| <b>Table 1.9 Emissions considered insignificant and reported as NE. Excluding LULUCF.</b> |                                                           |                                                      |                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>CRF code</b>                                                                           | Description of emission source                            | Gases                                                | Likely level of emissions (tonnes CO <sub>2</sub> equivalents)                                                                                                                                                                                                                                                                               |
| <b>1C1a</b>                                                                               | CO <sub>2</sub> transport and storage; Pipelines          | CO <sub>2</sub>                                      | Less than 200 tonnes. See chapter 3.5.                                                                                                                                                                                                                                                                                                       |
| <b>3A4, 3B4</b>                                                                           | Other animals: Enteric fermentation and manure management | CH <sub>4</sub> , N <sub>2</sub> O                   | See chapter 6.2. Includes ostrich, llama, etc. Emissions from ostrich were reported in previous submissions and were less than 500 t CO <sub>2</sub> eq when population was highest. Other animals have smaller populations.                                                                                                                 |
| <b>3D</b>                                                                                 | Agricultural soils                                        | CH <sub>4</sub>                                      | No methodology, see note to CRF Table3s2.                                                                                                                                                                                                                                                                                                    |
| <b>5C1</b>                                                                                | Cremation                                                 | CH <sub>4</sub> , N <sub>2</sub> O                   | No methodology.<br><br>NO <sub>x</sub> emissions from cremation is reported in 5C as 10-15 tonnes/year. CH <sub>4</sub> and N <sub>2</sub> O emission factors for combustion are generally lower than NO <sub>x</sub> factors, so the NO <sub>x</sub> emission is likely an upper bound.<br>Biogenic CO <sub>2</sub> is also reported as NE. |
| <b>5C2</b>                                                                                | Open burning of waste                                     | CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O | Order of 1200 t CO <sub>2</sub> eq. by estimate from 1999.                                                                                                                                                                                                                                                                                   |
|                                                                                           | Total                                                     |                                                      | Estimated emissions less than 2000 t CO <sub>2</sub> eq.                                                                                                                                                                                                                                                                                     |

For the LULUCF sector the notation key NE was used to report the following sources, either because they were non-mandatory or considered negligible. Further details are provided in chapter 6.1.5 and the table below.

| <b>Table 1.10 Emissions reported as NE for LULUCF.</b> |                                                   |                                                        |                                                                                                                                                                                                    |
|--------------------------------------------------------|---------------------------------------------------|--------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CRF code                                               | Description of emission source                    | Gases                                                  | Explanation                                                                                                                                                                                        |
| 4D1                                                    | Wetlands – flooded land remaining flooded land    | CO <sub>2</sub>                                        | It is not mandatory because there is no default method for estimating carbon stock changes for this source.                                                                                        |
| 4D2                                                    | Wetlands – land converted to peat extraction      | CO <sub>2</sub>                                        | Estimated to less than 10 000 t CO <sub>2</sub> eq and hence considered to be a negligible source. See chapter 6.7.3.                                                                              |
| 4(II)                                                  | Emissions from drainage and rewetting             | CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O | It is not mandatory to estimate emissions from rewetting organic or mineral soils.                                                                                                                 |
| 4(V)                                                   | Biomass burning – controlled burning- forest land | CH <sub>4</sub> and N <sub>2</sub> O                   | We assume emission from controlled forest fires are negligible because very few fire drills are performed. Emissions are estimated to less than 50 t CO <sub>2</sub> eq. See chapter 6.15.1.5.     |
| 4(V)                                                   | Biomass burning- wildfires – grassland            | CH <sub>4</sub> and N <sub>2</sub> O                   | We assume emission from wildfires on grasslands are negligible because these very rarely occur. Emissions are estimated to be in the range of 800-6 800 t CO <sub>2</sub> eq. See chapter 6.15.1.5 |
|                                                        | Total                                             |                                                        | Estimated emissions less than 17 000 t CO <sub>2</sub> eq.                                                                                                                                         |

Source: Norwegian Institute of Bioeconomy Research (NIBIO)

## 2. Trends in Greenhouse Gas Emissions

### 2.1 Description and interpretation of emission trends for aggregated GHG emissions

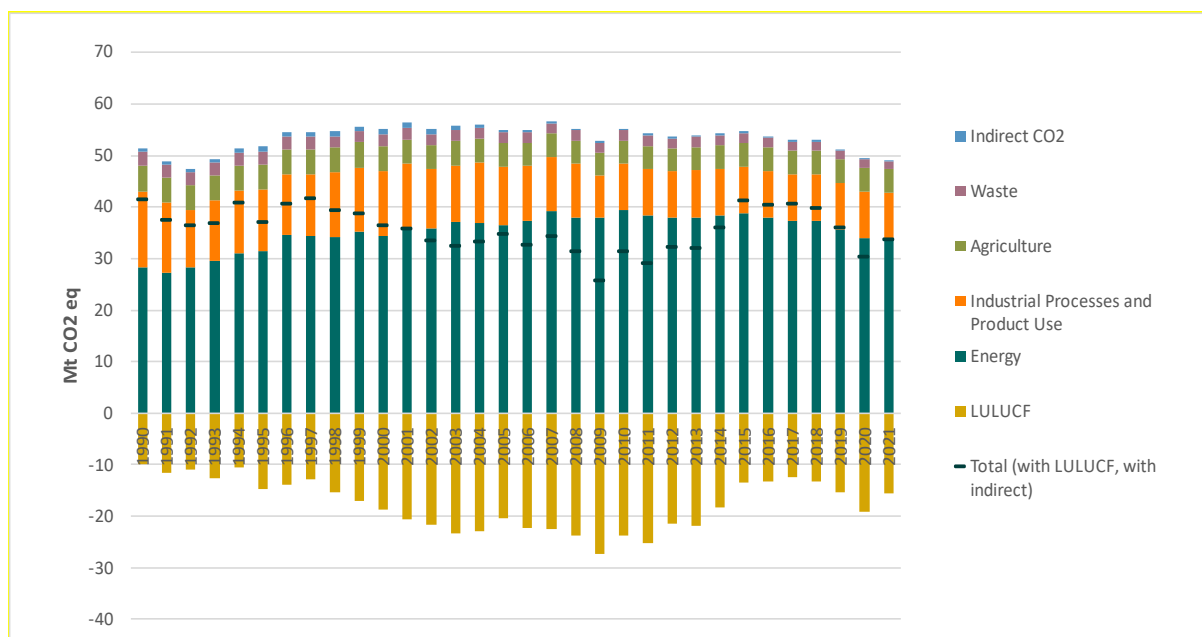
In 2021, total greenhouse gas (GHG) emissions in Norway were 49.2 million tonnes of carbon dioxide equivalents, which is a decrease of 0.3 million tonnes compared to 2020. Emissions reached their peak at 56.7 million tonnes in 2007. They have since decreased by 13 per cent, and were in 2021 2.1 million tonnes, or 4.2 per cent, lower than in 1990. The net GHG emissions, including all sources and sinks, were 33.7 million tonnes of CO<sub>2</sub> equivalents in 2021. The total emissions distribution among the CRF sectors from 1990 to 2021, as well as net removals in the LULUCF sector, are illustrated in Figure 2-1.

In this NIR, if not specified otherwise, total emission figures include indirect CO<sub>2</sub> emissions<sup>3</sup> but not emissions and removals from land use, land-use change and forestry (LULUCF). The indirect CO<sub>2</sub> emissions are further described in chapter 9.

The CO<sub>2</sub> equivalent values in this NIR are calculated with GWP values from IPCC AR5. This affects emission values and trends presented in CO<sub>2</sub> equivalents, including emissions levels expressed as CO<sub>2</sub>-equivalents by gas (chapter 2.2) and by sectors (chapter 2.3).

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<sup>3</sup> Non-CO<sub>2</sub>, carbon-containing gases (methane (CH<sub>4</sub>), CO or NMVOC) will eventually be oxidised to CO<sub>2</sub> in the atmosphere. The CO<sub>2</sub> emissions formed are termed "indirect CO<sub>2</sub> emissions".



*Figure 2-1. Total emissions of greenhouse gases by sources and removals from LULUCF in Norway, 1990-2021 (Mtonnes CO<sub>2</sub> equivalents). Source: Statistics Norway/Norwegian Environment Agency/Norwegian Institute of Bioeconomy Research*

Table 2.1 presents the total emissions and the distribution among the CRF sectors from 1990 to 2021. Total indirect CO<sub>2</sub> emissions and net removal from LULUCF are also presented in this table.



| <b>Table 2.1 Total emissions of greenhouse gases by sources and removals in Norway 1990-2021.<br/>Million tonnes of CO<sub>2</sub> equivalents.</b> |        |                                      |             |        |       |                                    |                                                        |                                                     |                                                           |                                                        |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------|--------------------------------------|-------------|--------|-------|------------------------------------|--------------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------|--------------------------------------------------------|
| Year                                                                                                                                                | Energy | Industrial processes and product use | Agriculture | LULUCF | Waste | Indirect CO <sub>2</sub> emissions | Total with indirect CO <sub>2</sub> and without LULUCF | Total with indirect CO <sub>2</sub> and with LULUCF | Total without indirect CO <sub>2</sub> and without LULUCF | Total without indirect CO <sub>2</sub> and with LULUCF |
| 1990                                                                                                                                                | 28.4   | 14.7                                 | 4.9         | -9.8   | 2.7   | 0.6                                | 51.3                                                   | 41.5                                                | 50.7                                                      | 40.9                                                   |
| 1995                                                                                                                                                | 31.5   | 11.9                                 | 4.9         | -14.7  | 2.6   | 0.9                                | 51.7                                                   | 37.0                                                | 50.8                                                      | 36.1                                                   |
| 2000                                                                                                                                                | 34.3   | 12.8                                 | 4.7         | -18.7  | 2.3   | 1.0                                | 55.1                                                   | 36.4                                                | 54.1                                                      | 35.4                                                   |
| 2005                                                                                                                                                | 36.5   | 11.2                                 | 4.7         | -20.3  | 2.0   | 0.5                                | 55.0                                                   | 34.7                                                | 54.5                                                      | 34.1                                                   |
| 2010                                                                                                                                                | 39.5   | 8.9                                  | 4.5         | -23.8  | 2.0   | 0.3                                | 55.2                                                   | 31.4                                                | 54.9                                                      | 31.1                                                   |
| 2011                                                                                                                                                | 38.4   | 9.0                                  | 4.5         | -25.2  | 2.1   | 0.3                                | 54.3                                                   | 29.1                                                | 54.0                                                      | 28.8                                                   |
| 2012                                                                                                                                                | 38.0   | 9.0                                  | 4.5         | -21.4  | 2.0   | 0.3                                | 53.7                                                   | 32.3                                                | 53.4                                                      | 32.0                                                   |
| 2013                                                                                                                                                | 38.0   | 9.1                                  | 4.5         | -21.9  | 2.0   | 0.3                                | 53.9                                                   | 32.0                                                | 53.6                                                      | 31.7                                                   |
| 2014                                                                                                                                                | 38.3   | 9.1                                  | 4.6         | -18.2  | 1.9   | 0.3                                | 54.2                                                   | 36.0                                                | 53.9                                                      | 35.7                                                   |
| 2015                                                                                                                                                | 38.7   | 9.1                                  | 4.7         | -13.4  | 1.9   | 0.3                                | 54.7                                                   | 41.3                                                | 54.4                                                      | 41.0                                                   |
| 2016                                                                                                                                                | 37.9   | 9.0                                  | 4.7         | -13.3  | 1.8   | 0.3                                | 53.8                                                   | 40.4                                                | 53.4                                                      | 40.1                                                   |
| 2017                                                                                                                                                | 37.2   | 9.0                                  | 4.7         | -12.4  | 1.7   | 0.3                                | 53.0                                                   | 40.5                                                | 52.7                                                      | 40.2                                                   |
| 2018                                                                                                                                                | 37.3   | 9.1                                  | 4.7         | -13.3  | 1.7   | 0.3                                | 53.0                                                   | 39.7                                                | 52.7                                                      | 39.4                                                   |
| 2019                                                                                                                                                | 35.7   | 9.1                                  | 4.6         | -15.3  | 1.6   | 0.3                                | 51.2                                                   | 35.9                                                | 51.0                                                      | 35.7                                                   |
| 2020                                                                                                                                                | 34.0   | 9.0                                  | 4.6         | -19.2  | 1.5   | 0.3                                | 49.5                                                   | 30.3                                                | 49.2                                                      | 30.0                                                   |
| 2021                                                                                                                                                | 33.7   | 9.0                                  | 4.7         | -15.5  | 1.4   | 0.3                                | 49.2                                                   | 33.7                                                | 48.9                                                      | 33.4                                                   |

Source: Statistics Norway/Norwegian Environment Agency/Norwegian Institute of Bioeconomy Research

Figure 2-2 illustrates the development of GHG emissions from the main sectors relative to 1990.

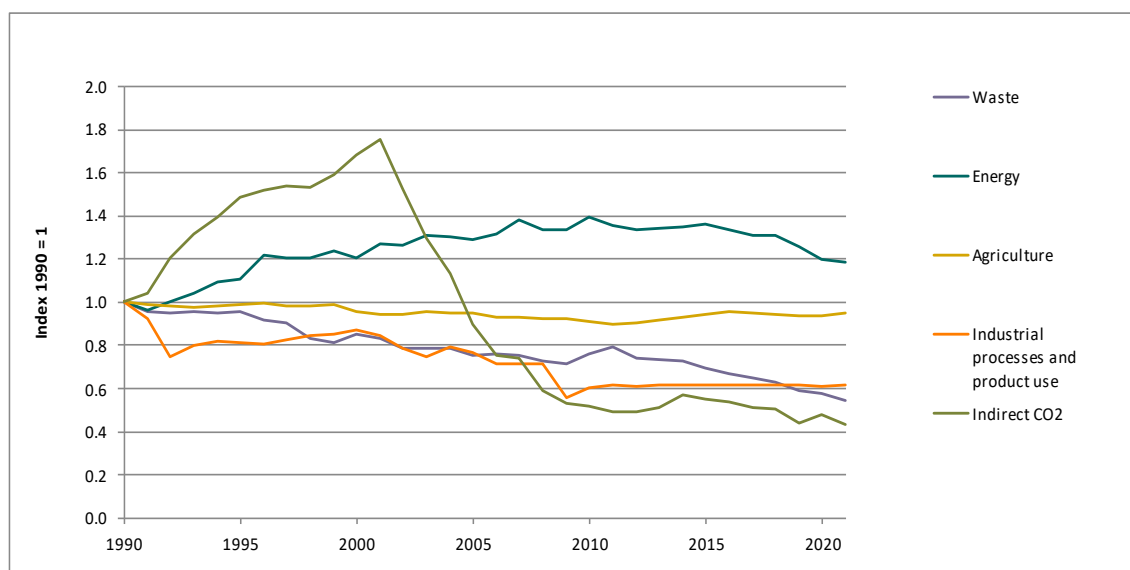


Figure 2-2. Changes in emissions of greenhouse gases, relative to 1990, by sectors, 1990-2021.

The development in indirect CO<sub>2</sub> emissions is also shown. Index 1990 = 1. Source: Statistics

Norway/Norwegian Environment Agency

Norway has experienced economic growth since 1990. In addition, the offshore petroleum sector has expanded significantly for the past 21 years. Together this has resulted in higher CO<sub>2</sub> emissions from energy use, both in energy industries and transport. Looking at the overall trend from 1990 to 2021, emissions from the energy sector increased by 18.8 per cent.

The downward trend in GHG emissions from the sector "Industrial processes and product use" in the early 1990s, can be explained by the implementation of policies and measures in the metal industry, resulting in less emission intensive production methods. Later, in the 2000s, the decrease was largely caused by close-downs and production reductions, this also mainly in the metal industry.

Emissions from agriculture have decreased by 5.0 per cent since 1990 mainly due to reduction of activity in the agriculture sector. The downward trend in GHG emissions from the waste sector is due to reductions of waste amounts disposed at disposal sites.

In chapter 2.2 and 2.3, emission trends are explained both by gas and by sector for the period 1990-2021.

## 2.2 Description and interpretation of emission trends by gas

As shown in Figure 2-3, CO<sub>2</sub> is by far the largest contributor to the total GHG emissions, followed by CH<sub>4</sub>, N<sub>2</sub>O, and the fluorinated gases (PFCs, SF<sub>6</sub> and HFCs). The relative share of the gases has been quite stable since 2010. However, the relative share of CO<sub>2</sub> increased steadily from 68.2 per cent in 1990 up to 82.7 per cent in 2010.

The CO<sub>2</sub> equivalent values in this NIR are calculated with GWP values from IPCC AR5, as opposed to AR4 values in last NIR. This has affected the emissions levels and shares presented in this chapter.

Table 2.2 presents emission figures for all greenhouse gases, expressed in absolute emission figures or CO<sub>2</sub> equivalents.

| <b>Table 2.2 Emissions of greenhouse gases in Norway, 1990-2021.</b> |                 |                 |                  |                             |                 |        |
|----------------------------------------------------------------------|-----------------|-----------------|------------------|-----------------------------|-----------------|--------|
| <i>Gas</i>                                                           | CO <sub>2</sub> | CH <sub>4</sub> | N <sub>2</sub> O | PFC                         | SF <sub>6</sub> | HFC    |
| <i>Year</i>                                                          | <i>Mt</i>       | <i>kt</i>       |                  | <i>kt CO<sub>2</sub> eq</i> |                 |        |
| 1990                                                                 | 35.0            | 249.4           | 13.8             | 3499.8                      | 2163.0          | 0.0    |
| 1995                                                                 | 38.5            | 256.8           | 12.4             | 2078.9                      | 597.6           | 91.9   |
| 2000                                                                 | 42.1            | 247.1           | 12.8             | 1364.1                      | 918.6           | 356.7  |
| 2005                                                                 | 43.3            | 229.7           | 13.6             | 858.2                       | 306.0           | 528.1  |
| 2010                                                                 | 45.7            | 223.1           | 8.2              | 214.3                       | 70.6            | 855.4  |
| 2011                                                                 | 44.8            | 218.2           | 8.2              | 236.1                       | 55.3            | 923.2  |
| 2012                                                                 | 44.3            | 214.4           | 8.2              | 180.3                       | 54.2            | 979.9  |
| 2013                                                                 | 44.6            | 211.2           | 8.2              | 162.8                       | 57.1            | 1068.1 |
| 2014                                                                 | 45.0            | 209.0           | 8.2              | 160.9                       | 50.3            | 1028.1 |
| 2015                                                                 | 45.5            | 208.9           | 8.3              | 131.6                       | 69.7            | 909.9  |
| 2016                                                                 | 44.7            | 205.4           | 8.1              | 167.4                       | 63.1            | 950.7  |
| 2017                                                                 | 44.1            | 199.8           | 8.0              | 117.8                       | 58.0            | 972.6  |
| 2018                                                                 | 44.3            | 196.6           | 7.9              | 133.1                       | 55.5            | 939.7  |
| 2019                                                                 | 42.7            | 189.3           | 8.0              | 157.4                       | 70.1            | 874.5  |
| 2020                                                                 | 41.2            | 188.9           | 7.8              | 145.2                       | 76.0            | 749.8  |
| 2021                                                                 | 40.9            | 187.7           | 7.8              | 222.8                       | 62.5            | 628.4  |

Source: Statistics Norway/Norwegian Environment Agency

**Table 2.3 Emissions in Mtonnes CO<sub>2</sub> equivalents and changes in per cent for each greenhouse gas.**

| Year              | CO <sub>2</sub> | CH <sub>4</sub> | N <sub>2</sub> O | PFCs    | SF <sub>6</sub> | HFCs        | Total with indirect CO <sub>2</sub> and without LULUCF |
|-------------------|-----------------|-----------------|------------------|---------|-----------------|-------------|--------------------------------------------------------|
| 1990              | 35.0            | 7.0             | 3.6              | 3.5     | 2.2             | 0.00005     | 51.3                                                   |
| 2020              | 41.2            | 5.3             | 2.1              | 0.1     | 0.1             | 0.7         | 49.5                                                   |
| 2021              | 40.9            | 5.3             | 2.1              | 0.2     | 0.1             | 0.6         | 49.2                                                   |
| Changes 1990-2021 | 16.9 %          | -24.7 %         | -43.2 %          | -93.6 % | -97.1 %         | 1286245.5 % | -4.2 %                                                 |
| Changes 2020-2021 | -0.6 %          | -0.6 %          | 0.2 %            | 53.5 %  | -17.8 %         | -16.2 %     | -0.7 %                                                 |

Source: Statistics Norway/Norwegian Environment Agency

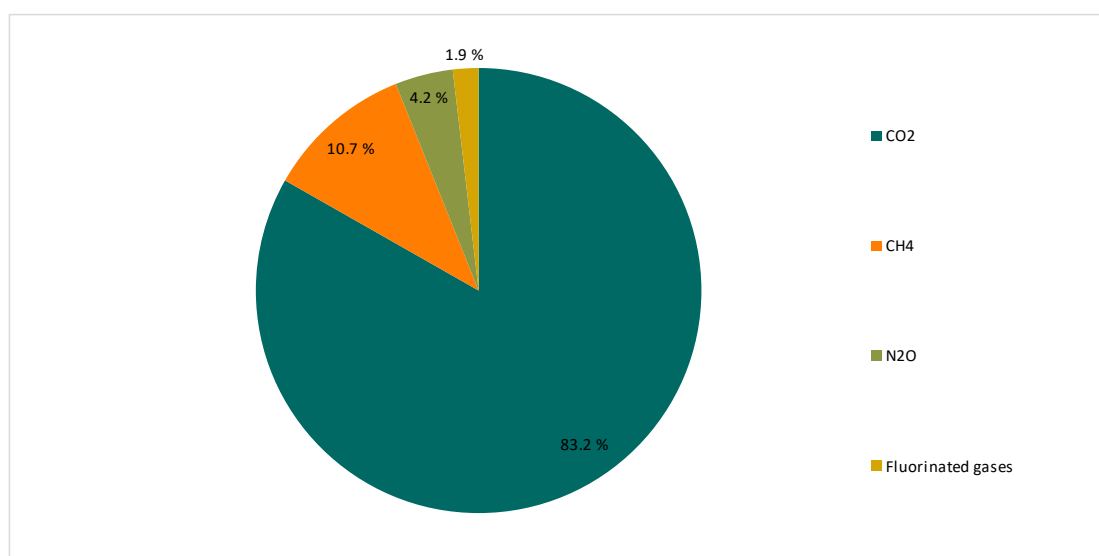


Figure 2-3 Distribution of emissions of greenhouse gases in Norway by gas (in CO<sub>2</sub> equivalents.), 2021. Source: Statistics Norway/Norwegian Environment Agency

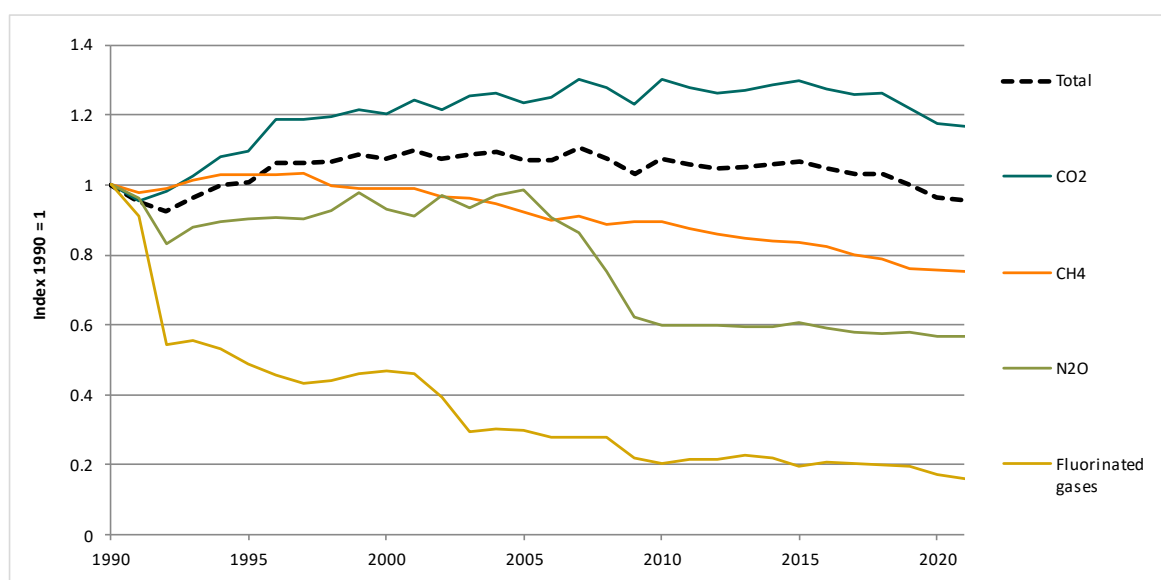


Figure 2-4 Changes in emissions of greenhouse gases, relative to 1990, by gas, 1990-2021. 'CO<sub>2</sub>' and 'Total' includes indirect CO<sub>2</sub>. Index 1990 = 1. Source: Statistics Norway/Norwegian Environment Agency

Table 2.3 presents the emissions in million tonnes per greenhouse gas and the changes in per cent for each greenhouse gas for the periods 1990–2021 and 2020–2021.

As presented in Table 2.2 and Table 2.3, CO<sub>2</sub> emissions increased significantly from 1990 to 2021 with 5.9 million tonnes. Emissions of CH<sub>4</sub> and N<sub>2</sub>O decreased by 1.7 and 1.6 million tonnes CO<sub>2</sub> equivalents, respectively. During the same period, PFCs and SF<sub>6</sub> emissions significantly decreased with 3.3 and 2.1 million tonnes CO<sub>2</sub> equivalents, respectively, while HFCs has increased from almost 0 to 0.6 million tonnes CO<sub>2</sub> equivalents.

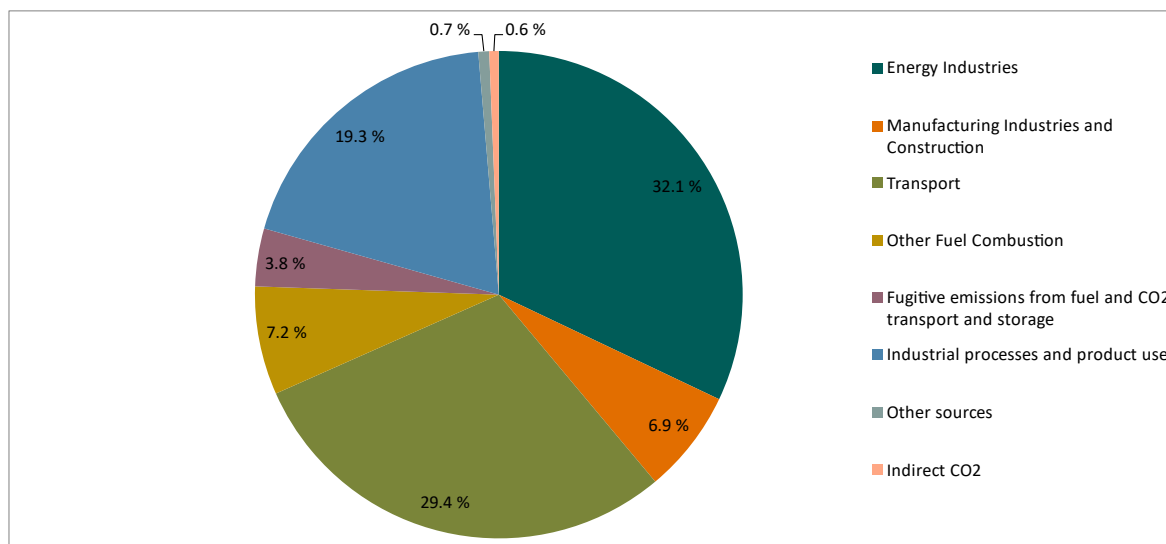
The fluorocarbons constituted a larger share of the GHG emission total in the early 1990s than in 2021, while CO<sub>2</sub> represented a smaller share in 1990 than in 2021.

Figure 2-4 illustrates the changes relative to 1990 for the different greenhouse gases for the period 1990 to 2021. The figure shows that the overall increasing total emission trend of CO<sub>2</sub> has been offset by decreased emissions of fluorinated gases (SF<sub>6</sub> and PFCs).

### 2.2.1 Carbon dioxide (CO<sub>2</sub>)

The Norwegian CO<sub>2</sub> emissions originate primarily from energy industries, transport, and industrial processes. Since generation of electricity is almost exclusively hydroelectric in Norway, emissions from stationary combustion are dominated by industrial sources and energy use.

The distribution of CO<sub>2</sub> emissions among various categories is shown in Figure 2-5.



*Figure 2-5. Distribution of CO<sub>2</sub> emissions in Norway by various source categories in 2021 (by mass). Source: Statistics Norway/Norwegian Environment Agency*

Table 2.4 lists CO<sub>2</sub> emissions from each source category for the period 1990-2021. The contributions to CO<sub>2</sub> emissions from the different categories from 1990 to 2021 are shown in Figure 2-6.

| Table 2.4 CO <sub>2</sub> emissions (million tonnes) from different source categories, 1990-2021. |                   |                                           |           |                       |                                                                        |                                      |                          |               |                                                        |
|---------------------------------------------------------------------------------------------------|-------------------|-------------------------------------------|-----------|-----------------------|------------------------------------------------------------------------|--------------------------------------|--------------------------|---------------|--------------------------------------------------------|
| Year                                                                                              | Energy Industries | Manufacturing Industries and Construction | Transport | Other Fuel Combustion | Fugitive emissions from fuel and CO <sub>2</sub> transport and storage | Industrial processes and product use | Indirect CO <sub>2</sub> | Other sources | Total with indirect CO <sub>2</sub> and without LULUCF |
| 1990                                                                                              | 7.1               | 3.4                                       | 9.8       | 4.4                   | 2.4                                                                    | 7.1                                  | 0.6                      | 0.2           | 35.0                                                   |
| 1995                                                                                              | 9.0               | 3.9                                       | 10.7      | 4.2                   | 2.0                                                                    | 7.6                                  | 0.9                      | 0.2           | 38.5                                                   |
| 2000                                                                                              | 10.8              | 3.4                                       | 11.7      | 3.4                   | 3.1                                                                    | 8.5                                  | 1.0                      | 0.2           | 42.1                                                   |
| 2005                                                                                              | 13.2              | 3.2                                       | 12.8      | 3.4                   | 2.3                                                                    | 7.7                                  | 0.5                      | 0.2           | 43.3                                                   |
| 2010                                                                                              | 14.7              | 3.3                                       | 13.7      | 3.6                   | 2.5                                                                    | 7.2                                  | 0.3                      | 0.3           | 45.7                                                   |
| 2011                                                                                              | 14.3              | 3.1                                       | 13.8      | 3.1                   | 2.5                                                                    | 7.4                                  | 0.3                      | 0.3           | 44.8                                                   |
| 2012                                                                                              | 14.0              | 3.0                                       | 13.9      | 3.0                   | 2.5                                                                    | 7.3                                  | 0.3                      | 0.3           | 44.3                                                   |
| 2013                                                                                              | 14.0              | 3.1                                       | 13.9      | 3.0                   | 2.5                                                                    | 7.4                                  | 0.3                      | 0.3           | 44.6                                                   |
| 2014                                                                                              | 14.7              | 2.9                                       | 14.3      | 2.8                   | 2.1                                                                    | 7.5                                  | 0.3                      | 0.4           | 45.0                                                   |
| 2015                                                                                              | 15.2              | 2.9                                       | 14.1      | 2.7                   | 2.4                                                                    | 7.6                                  | 0.3                      | 0.3           | 45.5                                                   |
| 2016                                                                                              | 14.7              | 2.8                                       | 13.6      | 3.1                   | 2.3                                                                    | 7.5                                  | 0.3                      | 0.3           | 44.7                                                   |
| 2017                                                                                              | 15.1              | 2.9                                       | 12.8      | 3.0                   | 2.1                                                                    | 7.6                                  | 0.3                      | 0.4           | 44.1                                                   |
| 2018                                                                                              | 14.9              | 3.0                                       | 13.0      | 3.0                   | 2.0                                                                    | 7.7                                  | 0.3                      | 0.4           | 44.3                                                   |
| 2019                                                                                              | 14.8              | 2.9                                       | 12.5      | 2.7                   | 1.5                                                                    | 7.7                                  | 0.3                      | 0.3           | 42.7                                                   |
| 2020                                                                                              | 14.1              | 2.7                                       | 11.8      | 2.8                   | 1.4                                                                    | 7.8                                  | 0.3                      | 0.4           | 41.2                                                   |
| 2021                                                                                              | 13.1              | 2.8                                       | 12.0      | 2.9                   | 1.6                                                                    | 7.9                                  | 0.3                      | 0.3           | 40.9                                                   |

Source: Statistics Norway/Norwegian Environment Agency

Since 1990, the total emissions of CO<sub>2</sub> have increased by 16.9 per cent, equalling 5.9 million tonnes. More use of natural gas in gas turbines in the oil and gas extraction industry have been the most important contributor to the overall increased emissions.

In 2021, the total Norwegian emissions of CO<sub>2</sub> were 40.9 million tonnes. There has been a downward trend in emissions since 2010, totalling 10.4 per cent, or 4.7 million tonnes, by 2021. Between 2020 and 2021, the emissions decreased by 0.6 per cent or 0.3 million tonnes.

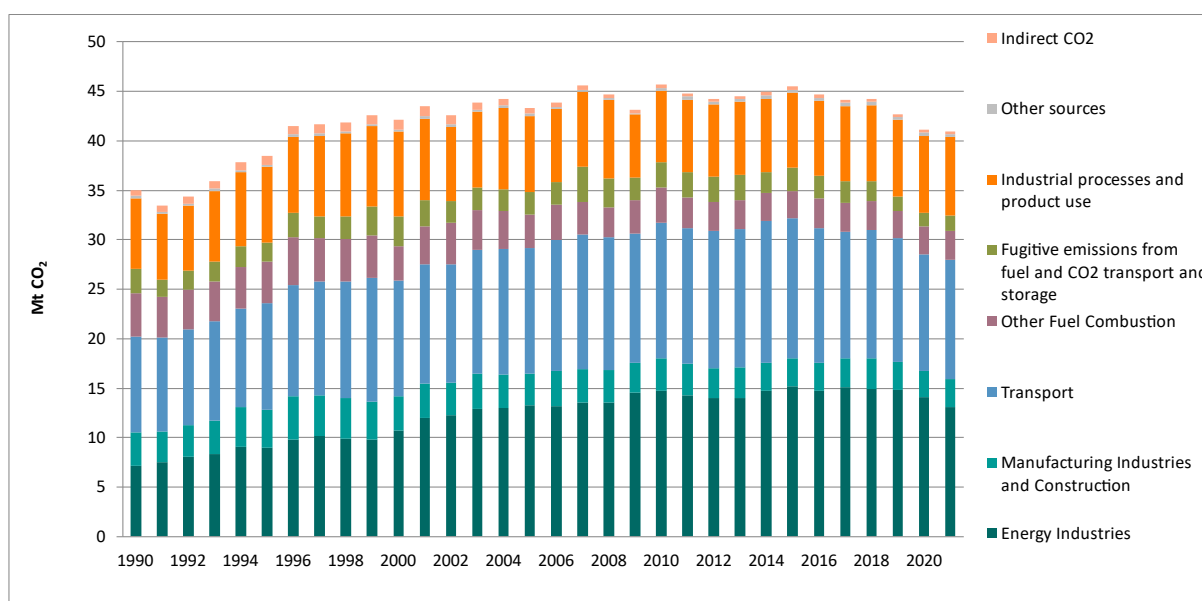


Figure 2-6. CO<sub>2</sub> emissions (Mtonnes) in Norway, 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

CO<sub>2</sub> emissions from energy industries have increased by 84.1 per cent since 1990 as a result of large increases in production volume of oil and gas and the export of natural gas in pipelines. In 2021, emissions from energy industries decreased by 1.0 million tonnes, or 6.9 per cent, compared to 2020.

CO<sub>2</sub> emissions from transport have increased by 23.5 per cent since 1990 and contributed to 29.4 per cent of the total CO<sub>2</sub> emissions in 2021. CO<sub>2</sub> emissions from this sector is dominated by road transportation which in 2021 accounted for 70.9 of the CO<sub>2</sub> emissions from transport.

CO<sub>2</sub> emissions from road transportation increased by 17.2 per cent between 1990 and 2021, although emissions from personal cars decreased by 16.7 per cent. CO<sub>2</sub> emissions from road transportation increased by 3.8 per cent between 2020 and 2021 due to increased sale of fossil fuels.

CO<sub>2</sub> emissions from industrial processes have increased by 10.4 per cent since 1990 and contributed to 19.3 per cent of total CO<sub>2</sub> emissions in 2021. Metal production is the biggest source and accounted for 64.5 per cent of the CO<sub>2</sub> emissions from industrial processes in 2021.



### 2.2.2 Methane (CH<sub>4</sub>)

In 2021, 56.4 per cent of methane emissions originated from agriculture, 20.1 per cent from the energy sector and 23.0 per cent from the waste sector. Methane emissions are dominated by releases from enteric fermentation in the agriculture sector, by fugitive emissions from oil and gas extraction in the energy sector and by landfills in the waste sector.

Figure 2-7 illustrates the distribution of Norwegian CH<sub>4</sub> emissions in 2021.

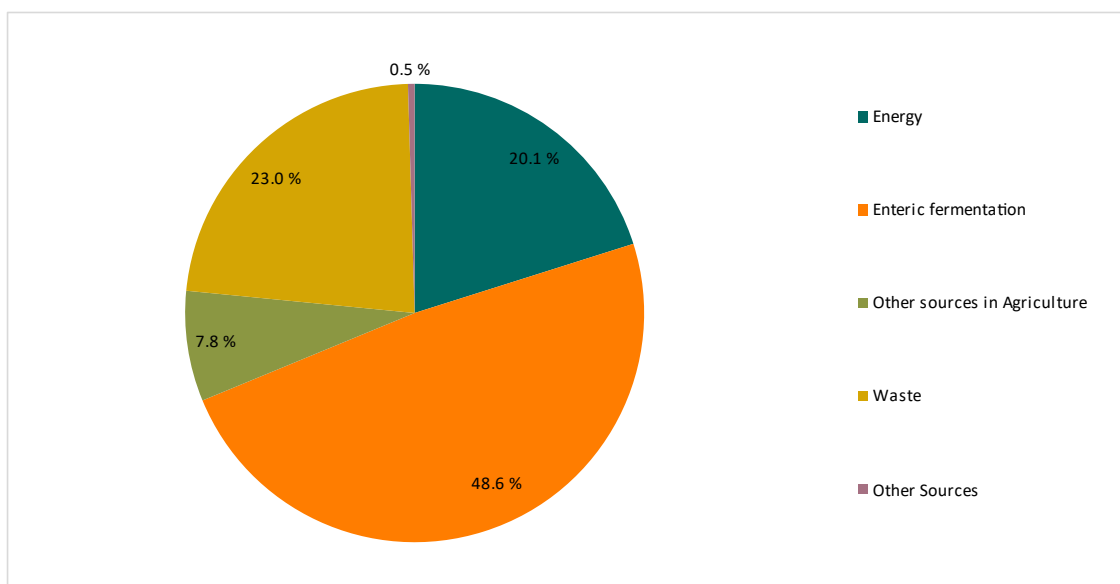


Figure 2-7. Distribution of Norwegian CH<sub>4</sub> emissions by major sources in 2021. Source: Statistics Norway/Norwegian Environment Agency

The methane figures from 1990 to 2021, distributed among major sources, are shown in Table 2.5.

| Table 2.5 Emissions of CH <sub>4</sub> (ktonnes) in Norway, 1990-2021. |        |                      |                              |       |               |                      |
|------------------------------------------------------------------------|--------|----------------------|------------------------------|-------|---------------|----------------------|
| Years                                                                  | Energy | Enteric fermentation | Other sources in Agriculture | Waste | Other Sources | Total without LULUCF |
| 1990                                                                   | 43.5   | 96.6                 | 14.6                         | 93.5  | 1.1           | 249.4                |
| 1995                                                                   | 55.3   | 97.2                 | 14.3                         | 88.9  | 1.1           | 256.8                |
| 2000                                                                   | 62.2   | 93.6                 | 13.7                         | 76.4  | 1.3           | 247.1                |
| 2005                                                                   | 55.7   | 92.9                 | 14.4                         | 65.6  | 1.1           | 229.7                |
| 2010                                                                   | 54.0   | 90.5                 | 14.8                         | 62.9  | 1.0           | 223.1                |
| 2011                                                                   | 51.0   | 88.1                 | 14.5                         | 63.6  | 1.0           | 218.2                |
| 2012                                                                   | 50.4   | 88.3                 | 14.6                         | 60.2  | 0.9           | 214.4                |
| 2013                                                                   | 47.6   | 89.2                 | 14.8                         | 58.7  | 0.9           | 211.2                |
| 2014                                                                   | 46.2   | 89.9                 | 15.0                         | 57.0  | 0.9           | 209.0                |
| 2015                                                                   | 46.7   | 91.3                 | 15.2                         | 54.7  | 0.9           | 208.9                |
| 2016                                                                   | 43.2   | 93.2                 | 15.4                         | 52.7  | 0.9           | 205.4                |
| 2017                                                                   | 41.1   | 93.0                 | 15.2                         | 49.6  | 0.9           | 199.8                |
| 2018                                                                   | 39.8   | 92.3                 | 15.2                         | 48.4  | 0.9           | 196.6                |
| 2019                                                                   | 38.3   | 89.7                 | 14.6                         | 45.8  | 0.8           | 189.3                |
| 2020                                                                   | 39.6   | 90.0                 | 14.4                         | 44.0  | 0.8           | 188.9                |
| 2021                                                                   | 37.8   | 91.3                 | 14.6                         | 43.2  | 0.9           | 187.7                |

Source: Statistics Norway/Norwegian Environment Agency

The total methane emissions decreased by 0.6 per cent from 2020 to 2021. Since 1990, CH<sub>4</sub> emissions have decreased by 24.7 per cent. Table 2.5 and Figure 2-8 show that this decrease is primarily due to the reduction of emissions from waste treatment.

The waste volumes have grown since 1990, but this effect has been more than offset by the increase of recycling, incineration of waste and burning of methane from landfills.

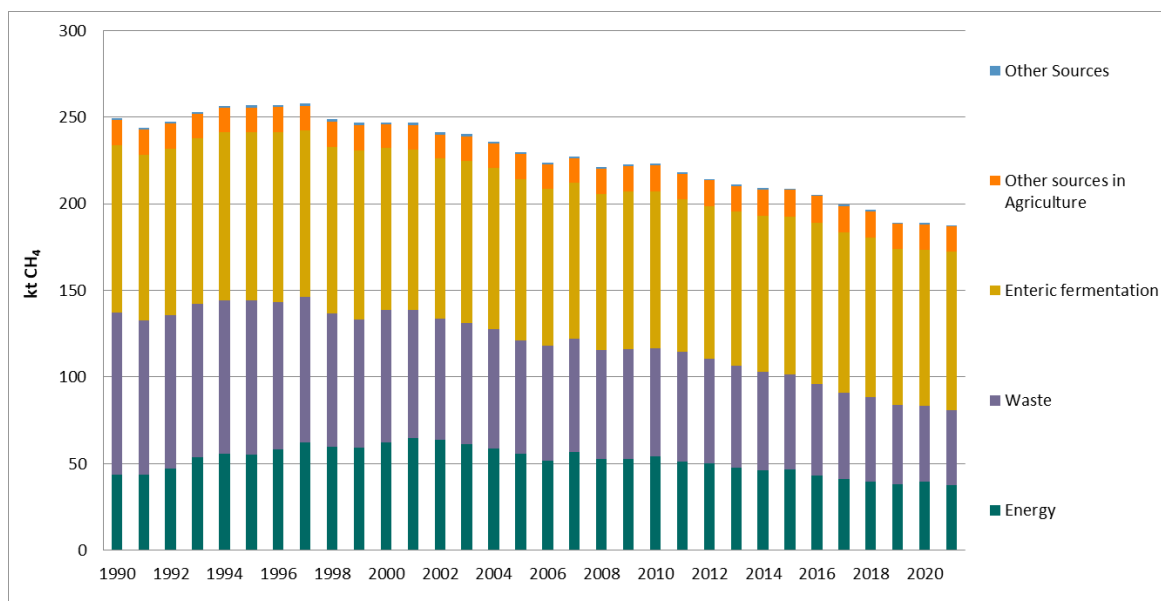
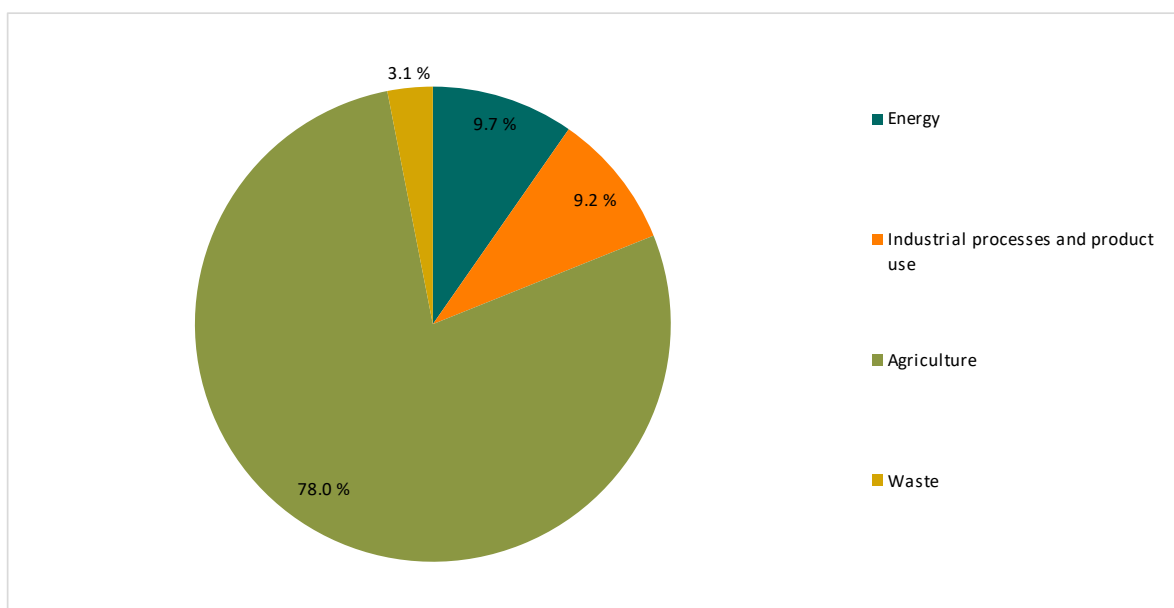


Figure 2-8. CH<sub>4</sub> emissions (ktonnes) in Norway, 1990-2021, without LULUCF. Source: Statistics Norway/Norwegian Environment Agency

### 2.2.3 Nitrous oxide (N<sub>2</sub>O)

Figure 2-9 shows that, in 2021, 78.0 per cent of the Norwegian N<sub>2</sub>O emissions are of agricultural origin, agricultural soils being the most prominent contributor within the agriculture sector. The energy sector, with transport being the biggest contributor, was the second biggest contributor, with 9.7 per cent. Industrial processes (almost entirely fertilizer and nitric acid production) accounted for 9.2 per cent of the N<sub>2</sub>O emissions in 2021, and the waste sector for 3.1 per cent. Emissions are dominated by road transport in the energy sector and by wastewater treatment and discharge in the waste sector.



*Figure 2-9. Distribution of Norwegian N<sub>2</sub>O emissions by major sources in 2021. Source: Statistics Norway/Norwegian Environment Agency*

During the period 1990–2021 the total N<sub>2</sub>O emissions decreased by 43.2 per cent. From 2020 to 2021, the emissions decreased by 0.2 per cent. Details are presented in [Table 2.6](#) and Figure 2-10. The decrease since 1990 is mainly due to reduced emissions from nitric acid production. The reduced emissions in the early 1990s were due to rebuilding of one production line in 1991. The reduced emissions from 2006 are due to the installation of the technology – N<sub>2</sub>O decomposition by extension of the reactor chamber.

| Table 2.6 Emissions of N <sub>2</sub> O (ktonnes) in Norway, 1990-2021. |        |                                      |             |       |                      |
|-------------------------------------------------------------------------|--------|--------------------------------------|-------------|-------|----------------------|
| Years                                                                   | Energy | Industrial processes and product use | Agriculture | Waste | Total without LULUCF |
| 1990                                                                    | 0.6    | 7.0                                  | 6.0         | 0.1   | 13.8                 |
| 1995                                                                    | 0.7    | 5.7                                  | 5.9         | 0.2   | 12.4                 |
| 2000                                                                    | 0.7    | 6.0                                  | 5.9         | 0.2   | 12.8                 |
| 2005                                                                    | 0.6    | 6.8                                  | 6.0         | 0.2   | 13.6                 |
| 2010                                                                    | 0.7    | 1.8                                  | 5.5         | 0.3   | 8.2                  |
| 2011                                                                    | 0.7    | 1.6                                  | 5.7         | 0.3   | 8.2                  |
| 2012                                                                    | 0.7    | 1.6                                  | 5.7         | 0.3   | 8.2                  |
| 2013                                                                    | 0.7    | 1.4                                  | 5.8         | 0.3   | 8.2                  |
| 2014                                                                    | 0.7    | 1.3                                  | 5.9         | 0.3   | 8.2                  |
| 2015                                                                    | 0.7    | 1.4                                  | 6.0         | 0.3   | 8.3                  |
| 2016                                                                    | 0.7    | 1.1                                  | 6.0         | 0.3   | 8.1                  |
| 2017                                                                    | 0.7    | 1.0                                  | 5.9         | 0.3   | 8.0                  |
| 2018                                                                    | 0.8    | 1.0                                  | 5.9         | 0.3   | 7.9                  |
| 2019                                                                    | 0.8    | 0.9                                  | 6.0         | 0.2   | 8.0                  |
| 2020                                                                    | 0.7    | 0.8                                  | 6.0         | 0.3   | 7.8                  |
| 2021                                                                    | 0.8    | 0.7                                  | 6.1         | 0.2   | 7.8                  |

Source: Statistics Norway/Norwegian Environment Agency

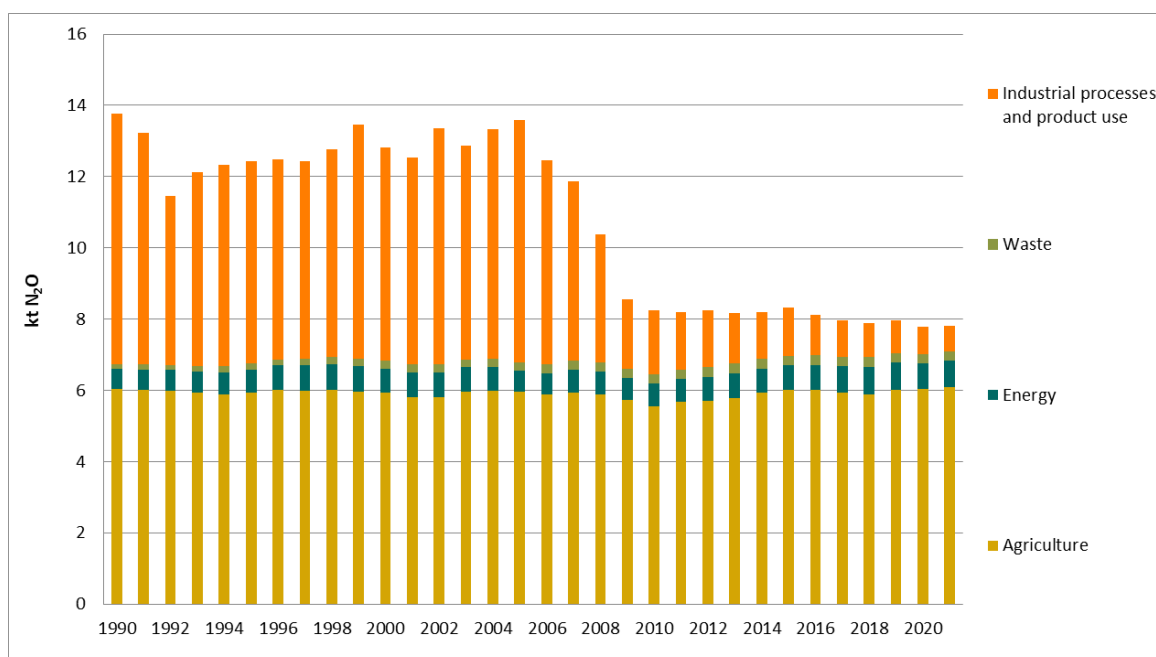


Figure 2-10. N<sub>2</sub>O emissions in Norway, 1990-2021, without LULUCF. Source: Statistics Norway/Norwegian Environment Agency

## 2.2.4 Perfluorocarbons (PFCs)

Aluminium production is the only source of PFC emissions in 2021. In 2021, the emissions of the perfluorocarbons tetrafluoromethane (CF<sub>4</sub>) and hexafluoroethane (C<sub>2</sub>F<sub>6</sub>) from Norwegian aluminium plants were reported at 28.1 tonnes and 3.3 tonnes respectively, corresponding to a total of 0.22 million tonnes of CO<sub>2</sub> equivalents. There were minor emissions of octafluoropropane (C<sub>3</sub>F<sub>8</sub>) from refrigeration in 2010-2014.

Total PFCs emissions have decreased by 93.6 per cent since 1990 following a steady downward trend as illustrated in Figure 2-11. Since 1990, emissions of CF<sub>4</sub> decreased by 94.0 per cent, while the emission of C<sub>2</sub>F<sub>6</sub> have gone down by 90.9 per cent.

Improvement of technology and process control in aluminium production led to a significant reduction in emissions. In 1990, PFCs emissions were 4.02 tonnes CO<sub>2</sub> equivalents per tonne aluminium produced. It was reduced to 0.63 tonnes CO<sub>2</sub> equivalents per tonne aluminium produced in 2007 and to 0.16 tonnes CO<sub>2</sub> equivalents per tonne aluminium produced in 2021. Total PFCs emissions increased by 0.08 million tonnes of CO<sub>2</sub> equivalents between 2020 and 2021 (see 2.3.2 for more details).

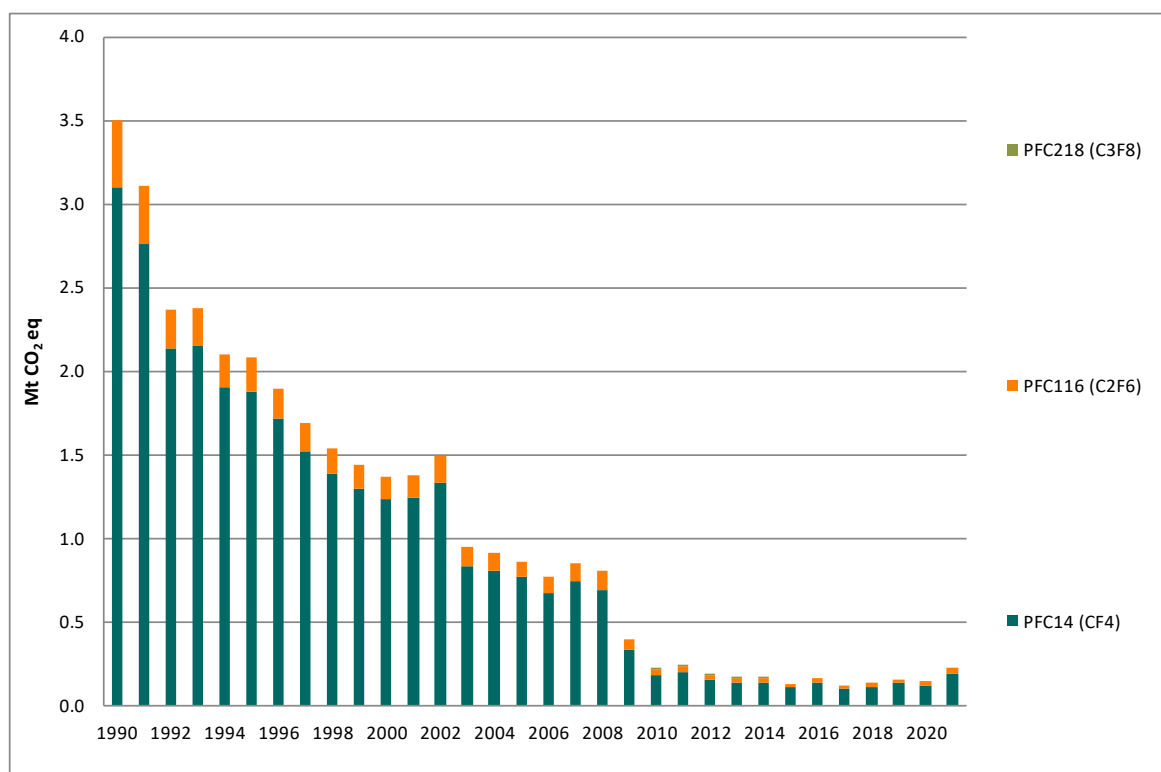


Figure 2-11. Emissions (million tonnes CO<sub>2</sub> eq) of PFCs in Norway, 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

| <b>Table 2.7 Emissions of PFCs in Norway in 1990-2021. Individual PFCs in tonnes, and totals in million tonnes of CO<sub>2</sub> eq.</b> |                              |                                             |                                             |                                |
|------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------------------------------|---------------------------------------------|--------------------------------|
| Year                                                                                                                                     | PFC14 (CF <sub>4</sub> ) (t) | PFC116 (C <sub>2</sub> F <sub>6</sub> ) (t) | PFC218 (C <sub>3</sub> F <sub>8</sub> ) (t) | Total CO <sub>2</sub> eq. (Mt) |
| 1990                                                                                                                                     | 467.4                        | 36.2                                        | -                                           | 3.5                            |
| 1995                                                                                                                                     | 283.3                        | 18.1                                        | -                                           | 2.1                            |
| 2000                                                                                                                                     | 186.4                        | 11.6                                        | -                                           | 1.4                            |
| 2005                                                                                                                                     | 116.7                        | 7.6                                         | -                                           | 0.9                            |
| 2010                                                                                                                                     | 27.3                         | 3.0                                         | 0.0028                                      | 0.2                            |
| 2011                                                                                                                                     | 29.9                         | 3.4                                         | 0.0031                                      | 0.2                            |
| 2012                                                                                                                                     | 22.9                         | 2.6                                         | 0.0029                                      | 0.2                            |
| 2013                                                                                                                                     | 20.6                         | 2.3                                         | 0.0013                                      | 0.2                            |
| 2014                                                                                                                                     | 20.3                         | 2.4                                         | 0.0000                                      | 0.2                            |
| 2015                                                                                                                                     | 16.7                         | 1.9                                         | -                                           | 0.1                            |
| 2016                                                                                                                                     | 21.2                         | 2.4                                         | -                                           | 0.2                            |
| 2017                                                                                                                                     | 14.9                         | 1.7                                         | -                                           | 0.1                            |
| 2018                                                                                                                                     | 16.9                         | 1.9                                         | -                                           | 0.1                            |
| 2019                                                                                                                                     | 20.0                         | 2.2                                         | -                                           | 0.2                            |
| 2020                                                                                                                                     | 18.3                         | 2.1                                         | -                                           | 0.1                            |
| 2021                                                                                                                                     | 28.1                         | 3.3                                         | -                                           | 0.2                            |

Source: Statistics Norway/Norwegian Environment Agency

### 2.2.5 Sulphur hexafluoride (SF<sub>6</sub>)

In 2021, the SF<sub>6</sub> emissions were 97.1 per cent lower than in 1990. Until 2006, the largest source of SF<sub>6</sub> emissions in Norway was magnesium production. The consumption of SF<sub>6</sub> was reduced through the 1990s due to improvements in technology and process management, and to reductions in production levels. Until 2002, SF<sub>6</sub> emission reductions were mainly due to the improved technology and process control within the metal industries. In 2002, production of cast magnesium closed, while production of secondary magnesium closed in 2006.

The main other use of SF<sub>6</sub> is in gas insulated switchgears (GIS) and other high-voltage applications. In 2002, a voluntary agreement was signed between the government and the business organisations representing most users of gas-insulated switchgear (GIS) as well as the single producer nationally. The agreement resulted in decreased emissions from these sources.



The increase in emissions in 2015 was due to decommissioning of sound insulated windows that was produced in Norway in the 1980s and 1990s.

**Table 2.8 SF6 emissions (tonnes), in Norway 1990-2021.**

| Year | Electrical equipment (t) | Magnesium and Aluminium Industry (t) | Other (t) | Total (t) |
|------|--------------------------|--------------------------------------|-----------|-----------|
| 1990 | 2.2                      | 89.7                                 | 0.1       | 92.0      |
| 1995 | 3.6                      | 21.3                                 | 0.5       | 25.4      |
| 2000 | 4.5                      | 32.4                                 | 2.3       | 39.1      |
| 2005 | 2.3                      | 10.0                                 | 0.6       | 13.0      |
| 2010 | 2.5                      | -                                    | 0.6       | 3.0       |
| 2011 | 1.9                      | -                                    | 0.4       | 2.4       |
| 2012 | 1.9                      | -                                    | 0.4       | 2.3       |
| 2013 | 2.0                      | -                                    | 0.4       | 2.4       |
| 2014 | 1.7                      | -                                    | 0.4       | 2.1       |
| 2015 | 1.7                      | -                                    | 1.3       | 3.0       |
| 2016 | 1.4                      | -                                    | 1.3       | 2.7       |
| 2017 | 1.0                      | -                                    | 1.5       | 2.5       |
| 2018 | 1.1                      | -                                    | 1.2       | 2.4       |
| 2019 | 1.8                      | -                                    | 1.2       | 3.0       |
| 2020 | 2.0                      | -                                    | 1.2       | 3.2       |
| 2021 | 1.4                      | -                                    | 1.2       | 2.7       |

Source: Statistics Norway/Norwegian Environment Agency

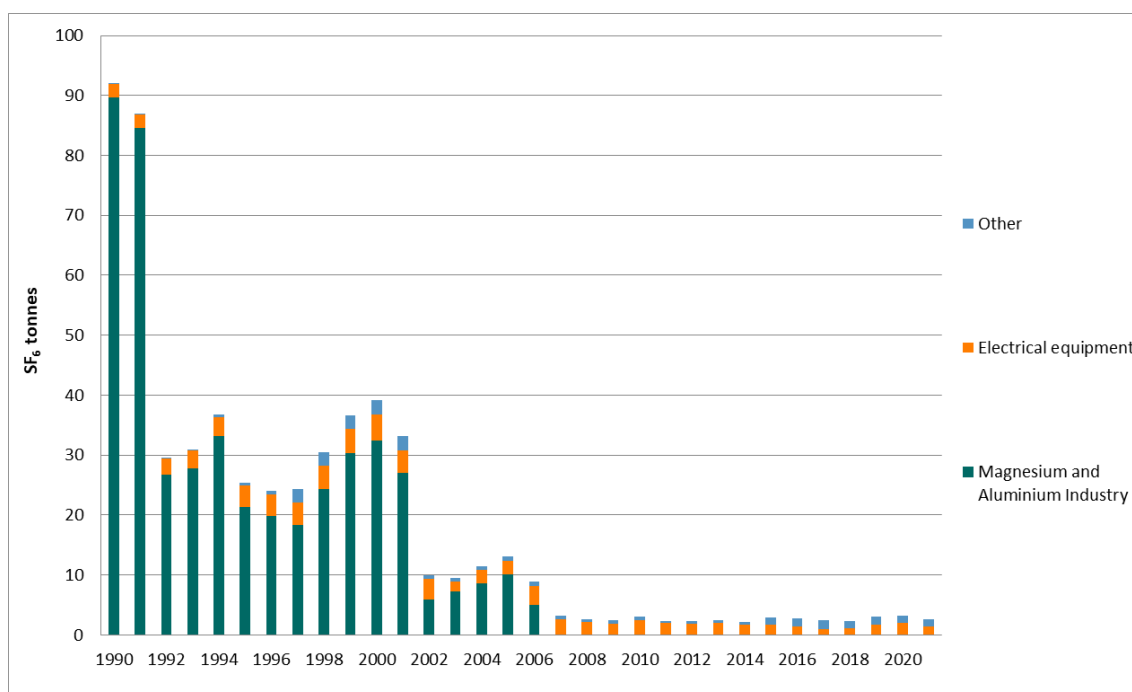


Figure 2-12. Emissions of SF<sub>6</sub> (tonnes) in Norway 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

### 2.2.6 Hydrofluorcarbons (HFCs)

The total emissions from HFCs used as substitutes for ozone depleting substances amounted to 0.6 million tonnes of CO<sub>2</sub> equivalents in 2021. The emissions in 1990 were insignificant (49 tonnes CO<sub>2</sub> equivalents) but have increased substantially over the years. The emissions decreased by 16.2 per cent from 2020 to 2021. This decrease was mainly caused by reduced emissions in 2.F.1.a, commercial refrigeration, 2.F.1.e, mobile air-conditioning, and 2.F.1.f, stationary air-conditioning. Emissions from these sources decreased by 25, 10 and 12 per cent from 2020 to 2021. There was also a decrease in 2.F.6.b, Contained, and 2.F.1.d, Transport refrigeration, by 40 per cent and 37 per cent, respectively. 2.F.1.c, Industrial refrigeration, experienced a rapid decline of 97 per cent between 2018 and 2020, and remained at a low level in 2021, constituting only 1 per cent of the total HFC emissions in 2021, down from 16 per cent in 2018. The recent and rapid decline of emissions in these sectors was mainly a consequence of restrictions from the EU F-gas regulation (implemented in Norway) which includes restrictions to place on the market refrigeration equipment that contains HFCs with GWP of 2500 and restricts the use of HFC refrigerants with GWP of 2500 or more for servicing and maintenance of refrigeration equipment.

The application category refrigeration and air conditioning contributes by far to the largest part of the HFCs emissions. The other categories foam/foam blowing, and fire extinguishing contributes to relatively small amounts to the overall emissions. Figure 2-13 displays the development of HFCs emissions since 1990 and [Table 2.9](#) presents HFCs emission values for different HFCs from 1990 to 2021.

| Table 2.9 Emissions of different specific HFCs (tonnes), unspecified mix of HFCs (Mtonnes CO <sub>2</sub> eq.) and total (Mtonnes CO <sub>2</sub> eq.) in Norway, 1990-2021. |              |            |            |                                                       |                                     |             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------------|------------|-------------------------------------------------------|-------------------------------------|-------------|
| Year                                                                                                                                                                         | HFC23 (t)    | HFC32 (t)  | HFC125 (t) | HFC134a (t)                                           | HFC143a (t)                         | HFC152a (t) |
| 1990                                                                                                                                                                         | -            | -          | -          | -                                                     | -                                   | 0.35        |
| 1995                                                                                                                                                                         | 0.00         | -          | 5.46       | 40.41                                                 | 4.06                                | 1.28        |
| 2000                                                                                                                                                                         | 0.06         | 0.73       | 34.17      | 68.70                                                 | 28.72                               | 1.77        |
| 2005                                                                                                                                                                         | 0.09         | 4.40       | 46.52      | 121.55                                                | 38.77                               | 0.91        |
| 2010                                                                                                                                                                         | 0.04         | 17.51      | 77.35      | 227.94                                                | 55.95                               | 1.36        |
| 2011                                                                                                                                                                         | 0.05         | 20.85      | 80.91      | 245.95                                                | 58.55                               | 1.18        |
| 2012                                                                                                                                                                         | 0.06         | 23.32      | 86.68      | 266.22                                                | 58.23                               | 0.62        |
| 2013                                                                                                                                                                         | 0.39         | 26.34      | 93.29      | 280.30                                                | 67.35                               | 5.26        |
| 2014                                                                                                                                                                         | 0.40         | 27.80      | 88.99      | 294.59                                                | 58.44                               | 0.14        |
| 2015                                                                                                                                                                         | 0.27         | 30.17      | 80.00      | 293.36                                                | 42.43                               | 0.16        |
| 2016                                                                                                                                                                         | 0.24         | 31.38      | 80.27      | 310.97                                                | 42.83                               | 0.21        |
| 2017                                                                                                                                                                         | 0.89         | 34.42      | 81.58      | 306.19                                                | 42.94                               | 0.20        |
| 2018                                                                                                                                                                         | 0.15         | 35.72      | 89.18      | 298.22                                                | 42.86                               | 0.26        |
| 2019                                                                                                                                                                         | 0.12         | 41.29      | 86.83      | 300.02                                                | 30.53                               | 0.44        |
| 2020                                                                                                                                                                         | 0.11         | 45.14      | 72.20      | 285.12                                                | 14.52                               | 0.74        |
| 2021                                                                                                                                                                         | 0.09         | 44.37      | 54.97      | 265.87                                                | 11.19                               | 0.95        |
| Year                                                                                                                                                                         | HFC227ea (t) | HFC134 (t) | HFC143 (t) | Unspecified mix of HFCs (Mtonnes CO <sub>2</sub> eq.) | Total (Mtonnes CO <sub>2</sub> eq.) |             |
| 1990                                                                                                                                                                         | -            | -          | -          | 0.00                                                  | 0.00                                |             |
| 1995                                                                                                                                                                         | -            | -          | -          | 0.00                                                  | 0.09                                |             |
| 2000                                                                                                                                                                         | -            | -          | -          | 0.02                                                  | 0.36                                |             |
| 2005                                                                                                                                                                         | -            | 0.56       | 0.65       | 0.03                                                  | 0.53                                |             |
| 2010                                                                                                                                                                         | -            | 0.96       | 0.61       | 0.03                                                  | 0.86                                |             |
| 2011                                                                                                                                                                         | -            | 0.94       | 0.58       | 0.05                                                  | 0.92                                |             |
| 2012                                                                                                                                                                         | 0.14         | 0.99       | 0.56       | 0.06                                                  | 0.98                                |             |
| 2013                                                                                                                                                                         | 0.17         | 0.96       | 0.54       | 0.06                                                  | 1.07                                |             |
| 2014                                                                                                                                                                         | 0.18         | 0.92       | 0.52       | 0.06                                                  | 1.03                                |             |
| 2015                                                                                                                                                                         | 0.21         | 0.89       | 0.50       | 0.05                                                  | 0.91                                |             |
| 2016                                                                                                                                                                         | 0.17         | 9.99       | 0.48       | 0.05                                                  | 0.95                                |             |
| 2017                                                                                                                                                                         | 0.15         | 0.45       | 9.44       | 0.07                                                  | 0.97                                |             |
| 2018                                                                                                                                                                         | 0.10         | 0.42       | 2.06       | 0.04                                                  | 0.94                                |             |
| 2019                                                                                                                                                                         | 0.09         | 0.46       | -          | 0.03                                                  | 0.87                                |             |
| 2020                                                                                                                                                                         | 0.05         | 9.05       | -          | 0.04                                                  | 0.75                                |             |
| 2021                                                                                                                                                                         | 0.17         | 0.06       | -          | 0.02                                                  | 0.63                                |             |

Source: Statistics Norway/Norwegian Environment Agency

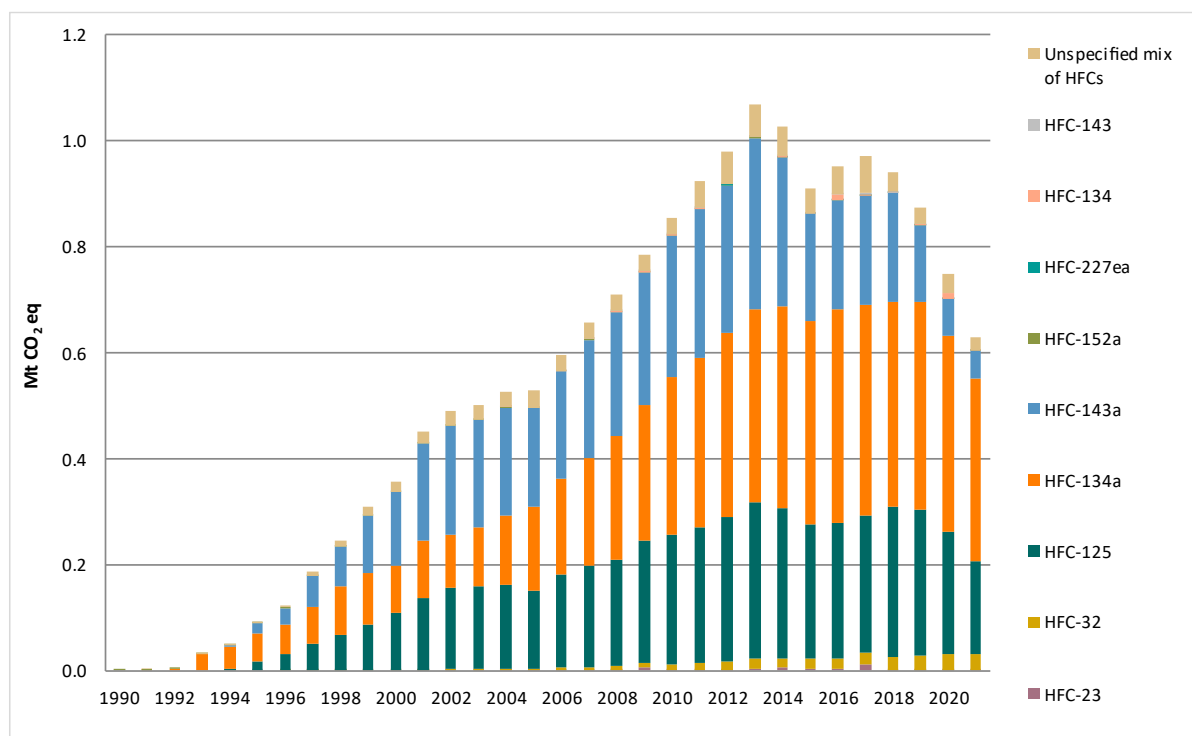
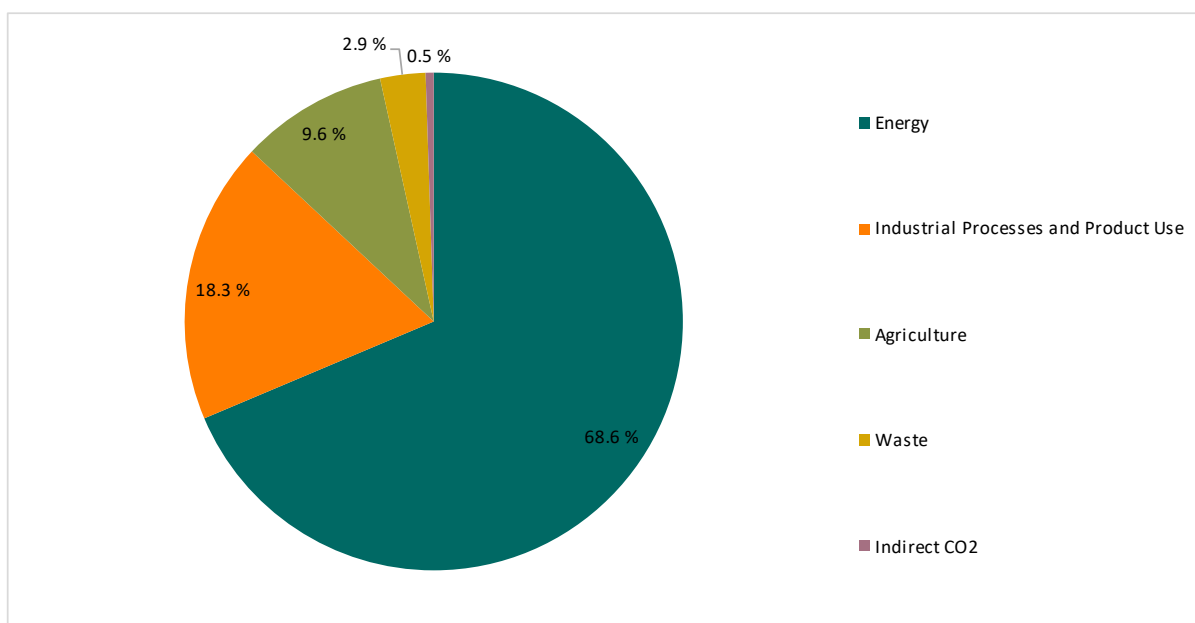


Figure 2-13. Emissions of HFCs (Mtonnes CO<sub>2</sub> eq.) in Norway, 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

## 2.3 Description and interpretation of emission trends by sector

Figure 2-14 illustrates the 2021 distribution of Norwegian GHG emissions by IPCC classification of sources. The energy sector is by far the most important source of emissions, contributing to 68.6 per cent of the national GHG emissions in 2021.

The CO<sub>2</sub> equivalent values in this NIR are calculated with GWP values from IPCC AR5, as opposed to AR4 values in last NIR. This has affected the emissions levels and shares presented in this chapter.



*Figure 2-14. Distribution of GHG emissions (without LULUCF) in Norway in 2021 by sector. Indirect CO<sub>2</sub> emissions are also shown. Source: Statistics Norway/Norwegian Environment Agency*

Figure 2-15 displays GHG emissions trends by sectors between 1990 and 2021. The energy sector is divided into its five categories: fuel combustion in energy industries, fuel combustion in manufacturing industries and construction, fuel combustion in transport, fuel combustion in other sectors<sup>4</sup>, and fugitive emissions from fuels.

While emissions have decreased for most of the sectors, emissions from energy industries and transport have increased considerably since 1990.

<sup>4</sup> Includes CRF key categories 1A4 (stationary combustion in agriculture, forestry, fishing, commercial and institutional sectors and households, motorized equipment and snow scooters in agriculture and forestry, and ships and boats in fishing) and 1A5 (fuel used in stationary and mobile military activities).

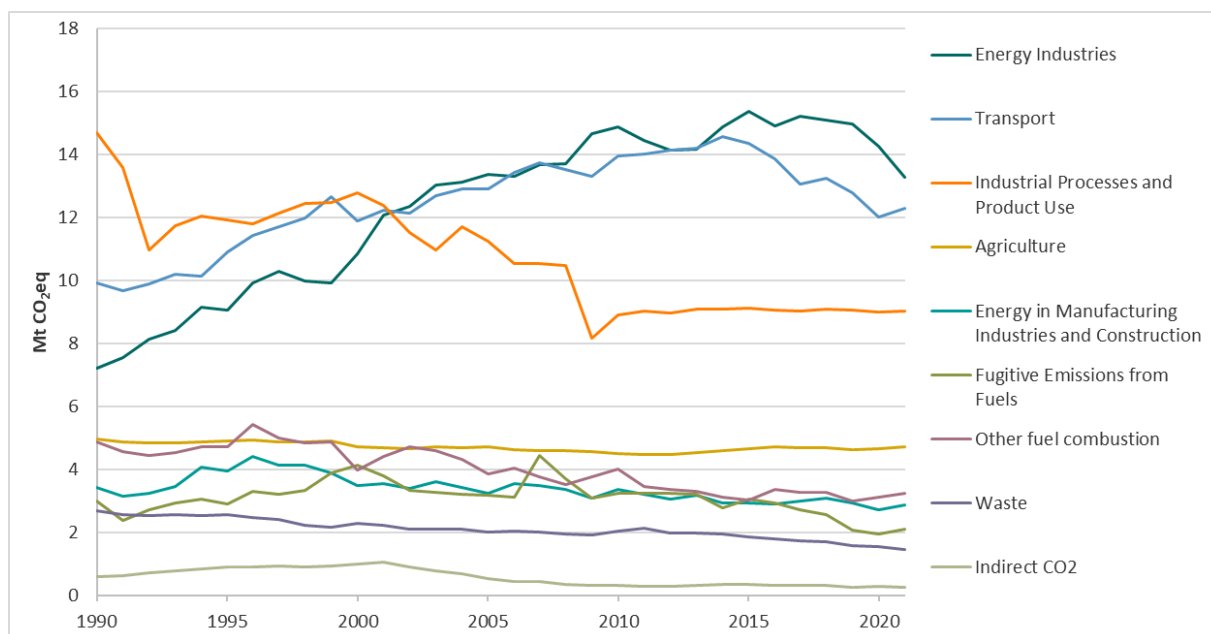
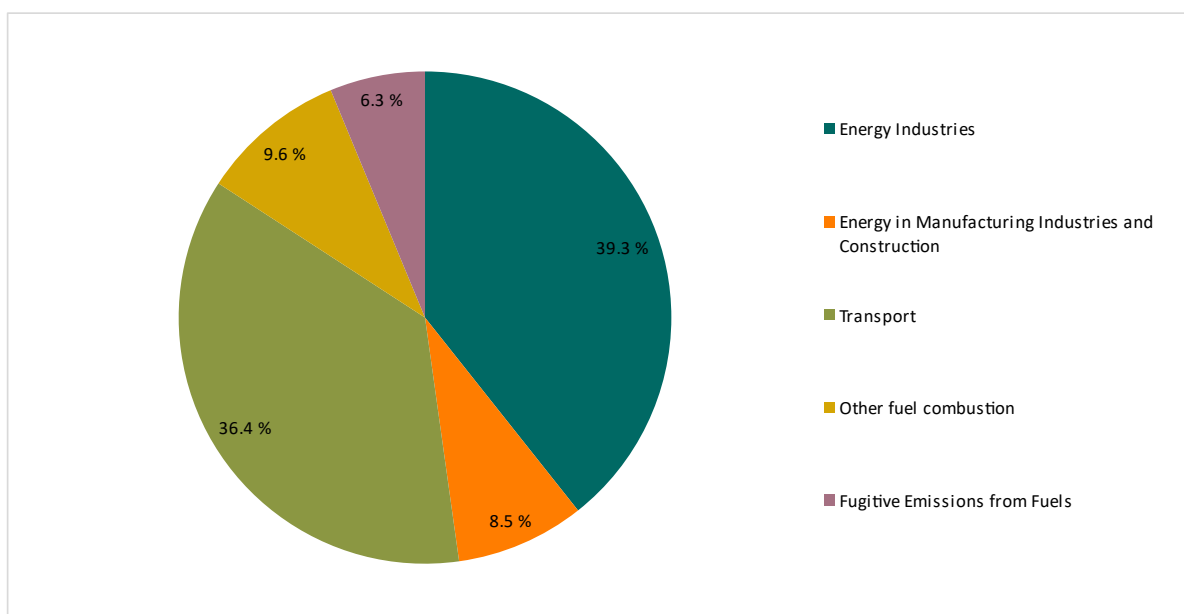


Figure 2-15. Development of emissions of all GHG (Mtonnes CO<sub>2</sub> eq.) from the different sectors (without LULUCF) 1990-2021. Indirect CO<sub>2</sub> emissions are also shown. Source: Statistics Norway/Norwegian Environment Agency

### 2.3.1 Energy

Figure 2-16 displays the distribution of GHG emissions in 2021 by the main categories within the energy sector.



*Figure 2-16. Greenhouse gas emissions in 2021 from the energy sector distributed among the different main source categories. Source: Statistics Norway/Norwegian Environment Agency*

The major sources of emissions within the energy sector are energy industries and transport, which contributed to 39.3 per cent and 36.4 per cent, respectively, of emissions from the energy sector in 2021. The remaining emissions are nearly equally shared between the categories energy use in manufacturing industries and construction, other fuel combustion and fugitive emissions from fuels.

The Norwegian electricity production is dominated by hydroelectric power. Thus, emissions from energy industries origin almost completely from fuel combustion in oil and gas extraction and related activities. Electricity is normally used in manufacturing processes and for heating purposes.

The total emissions of GHG from the energy sector over the period 1990-2021 are listed in [Table 2.10](#).



| <b>Table 2.10 Emissions of greenhouse gases (Mtonnes CO<sub>2</sub> eq.) from the energy sector in Norway, 1990-2021. Emissions from CO<sub>2</sub> transport and storage is presented in ktonnes CO<sub>2</sub> eq.</b> |                   |                                                     |           |                       |                               |                                       |       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-----------------------------------------------------|-----------|-----------------------|-------------------------------|---------------------------------------|-------|
| Year                                                                                                                                                                                                                     | Energy Industries | Energy in Manufacturing Industries and Construction | Transport | Other fuel combustion | Fugitive Emissions from Fuels | CO <sub>2</sub> transport and storage | Total |
| 1990                                                                                                                                                                                                                     | 7.2               | 3.4                                                 | 9.9       | 4.9                   | 3.0                           | 0.0                                   | 28.4  |
| 1995                                                                                                                                                                                                                     | 9.0               | 3.9                                                 | 10.9      | 4.7                   | 2.9                           | 0.0                                   | 31.5  |
| 2000                                                                                                                                                                                                                     | 10.8              | 3.5                                                 | 11.9      | 4.0                   | 4.1                           | 0.0                                   | 34.3  |
| 2005                                                                                                                                                                                                                     | 13.3              | 3.2                                                 | 12.9      | 3.8                   | 3.2                           | 0.0                                   | 36.5  |
| 2010                                                                                                                                                                                                                     | 14.9              | 3.4                                                 | 13.9      | 4.0                   | 3.2                           | 0.1                                   | 39.5  |
| 2011                                                                                                                                                                                                                     | 14.4              | 3.2                                                 | 14.0      | 3.5                   | 3.2                           | 0.1                                   | 38.4  |
| 2012                                                                                                                                                                                                                     | 14.1              | 3.1                                                 | 14.1      | 3.4                   | 3.2                           | 0.1                                   | 38.0  |
| 2013                                                                                                                                                                                                                     | 14.2              | 3.2                                                 | 14.2      | 3.3                   | 3.2                           | 0.0                                   | 38.0  |
| 2014                                                                                                                                                                                                                     | 14.9              | 2.9                                                 | 14.6      | 3.1                   | 2.8                           | 0.0                                   | 38.3  |
| 2015                                                                                                                                                                                                                     | 15.4              | 2.9                                                 | 14.3      | 3.0                   | 3.1                           | 0.0                                   | 38.7  |
| 2016                                                                                                                                                                                                                     | 14.9              | 2.9                                                 | 13.8      | 3.3                   | 2.9                           | 0.0                                   | 37.9  |
| 2017                                                                                                                                                                                                                     | 15.2              | 3.0                                                 | 13.1      | 3.3                   | 2.7                           | 0.0                                   | 37.2  |
| 2018                                                                                                                                                                                                                     | 15.1              | 3.1                                                 | 13.2      | 3.3                   | 2.6                           | 0.0                                   | 37.3  |
| 2019                                                                                                                                                                                                                     | 14.9              | 2.9                                                 | 12.8      | 3.0                   | 2.1                           | 0.0                                   | 35.7  |
| 2020                                                                                                                                                                                                                     | 14.2              | 2.7                                                 | 12.0      | 3.1                   | 2.0                           | 0.0                                   | 34.0  |
| 2021                                                                                                                                                                                                                     | 13.3              | 2.9                                                 | 12.3      | 3.2                   | 2.1                           | 0.0                                   | 33.7  |

Source: Statistics Norway/Norwegian Environment Agency

Emission changes from 1990 to 2021, relative to 1990, for various categories within the energy sector, are illustrated in Figure 2-17.

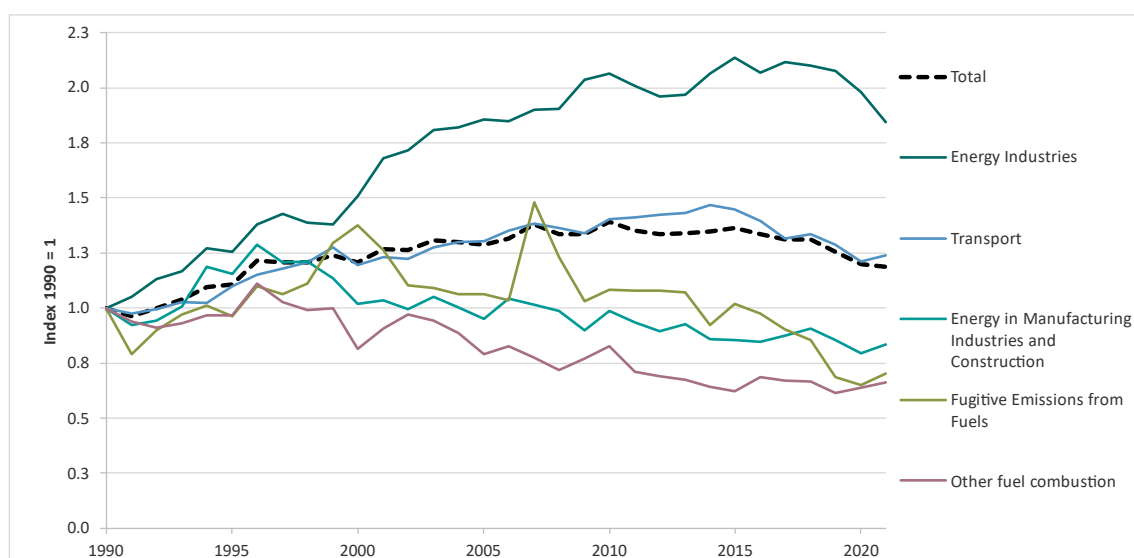


Figure 2-17. Changes in emissions of greenhouse gases, relative to 1990, for the main sub-sectors within the energy sector, 1990-2021. Index 1990 = 1. Source: Statistics Norway/Norwegian Environment Agency

The GHG emissions from the energy sector increased by 18.8 per cent from 1990 to 2021, primarily due to increased activity within oil and gas extraction and transport, specifically road transportation. Since 2015, emissions have decreased by 13 per cent. From 2020 to 2021, emissions decreased by 0.8 per cent. One important reason was a temporary shutdown of an LNG plant, which in years of normal operation reports emissions of around 1 million tonnes CO<sub>2</sub>.

Emissions from fuel combustion within the category energy industries were 84.5 per cent higher in 2021 than in 1990. The growth can be explained by the increase of oil and gas production and the increase of energy demand in extraction, due to aging of oil fields and transition from oil to gas. Oil and gas extraction is the main emission source within the category energy industries and has played an important role in the national economy in recent decades. On the offshore oil and gas installations, electricity and pumping power is principally produced by gas turbines, and to a lesser extent, diesel engines. The emissions from oil and gas extraction decreased by 7.9 per cent from 2020 to 2021.

In 2021, emissions from energy combustion in oil and gas extraction contributed to 22.4 per cent of the national GHG emissions. In 1990, the corresponding contribution was 11.5 per cent.

Electricity production is largely dominated by hydroelectric generation. Between 1990 and 2021, important exceptions are gas fired electricity power plants, waste incineration power plants and a small coal combustion plant (6 MW) on the island of Spitsbergen.

Emissions from manufacturing industries and construction reported in the energy sector (1A2) originate mainly from the less energy intensive industries. It should be noted that the largest emissions from energy consumption in manufacturing are reported in the IPPU sector, due to the reporting requirements in the IPCC guidelines<sup>5</sup>. This applies particularly to production of metals, ammonia and petrochemicals. Off-road vehicles and other machinery (1.A.2.g.vii) accounted for 41 per cent of the overall emissions from 1A2 in 2021, which makes it the biggest emission category within this source. Other major contributing categories are non-metallic mineral production (1.A.2.f), food processing (1.A.2.e) and non-ferrous metals (1.A.2.b). These contributed to respectively 23, 11 and 8 per cent of the total emissions from 1.A.2 in 2021.

Emissions from the manufacturing industries and construction in the energy sector decreased by 16.5 per cent from 1990 to 2021, and increased by 5.1 per cent from 2020 to 2021. In 2021, the emissions from this source category contributed to 5.8 per cent of national GHG emissions.

Emissions from the transport category increased by 23.8 per cent from 1990 to 2021, and increased by 2.3 per cent from 2020 to 2021. The emissions reached a peak of 14.6 million tonnes in 2014. The share of transport in the national total GHG emissions has increased from 19.3 per cent in 1990 to 25.0 per cent in 2021. In 2021, road transportation accounted for 70.5 per cent of emissions from the total transport emissions, while emissions from navigation and civil aviation accounted for 22.4 per cent and 6.6 per cent, respectively. Due to the fact that most railways are electrified in Norway, emissions of GHG from this source are insignificant.

GHG emissions from road transportation increased by 16.6 per cent from 1990 to 2021 and contributed to 17.6 per cent of the national GHG emissions in 2021. This trend is mainly due to the increase of activity in goods transport, as a response to higher economic activity. Emissions from road transport went up considerably from 1990 until 2007. They then were relatively stable until 2015 and have since plunged by 15.5 per cent from 2015 to 2021. In addition to reduced activity, the stabilised and decreased emissions observed from 2007

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<sup>5</sup> According to the IPCC Guidelines, emissions from all use of energy commodities such as coal, coke, LPG, and natural gas should be reported in the IPPU sector when some of the fuel is used as feedstock, reducing agent or other non-energy purposes. This is to avoid double counting or omissions.

could, in the first years after, be explained by the switch from petrol to diesel driven passenger cars, due to the implementation of a CO<sub>2</sub> differentiated tax in 2007. However, in the later years a blending requirement of biofuels has led to increased consumption of bio diesel and bio ethanol and hence reduced CO<sub>2</sub> emissions. In addition, the sales of electric vehicles have gradually increased since 2011 due to economic incentives and added up to 65 per cent of sold passenger cars and 16 per cent of sold light duty vehicles in 2021. From 2020 to 2021, emissions from road transport increased by 3.7 per cent due to increased sale of fossil fuels.

Navigation contributed to the national total GHG emissions by 5.6 per cent in 2021. During the period 1990-2021, emissions have increased by 63.8 per cent. Emissions from navigation increased mainly due to an increase of activity related to the oil and gas extraction sector.

Civil aviation contributed to 1.7 per cent of the national GHG emissions in 2021. Emissions from civil aviation have increased by 16.1 per cent since 1990. The substitution of older planes by new and more energy efficient planes has also played an important role to limit the emission growth. The emissions increased by 3.4 per cent from 2020 to 2021, a modest increase considering the emissions from civil aviation went down by 30 per cent from 2019 to 2020 due to reduced activity following travel restrictions.

GHG emission trends from the main transport modes are illustrated in Figure 2-18 and [Table 2.11](#).

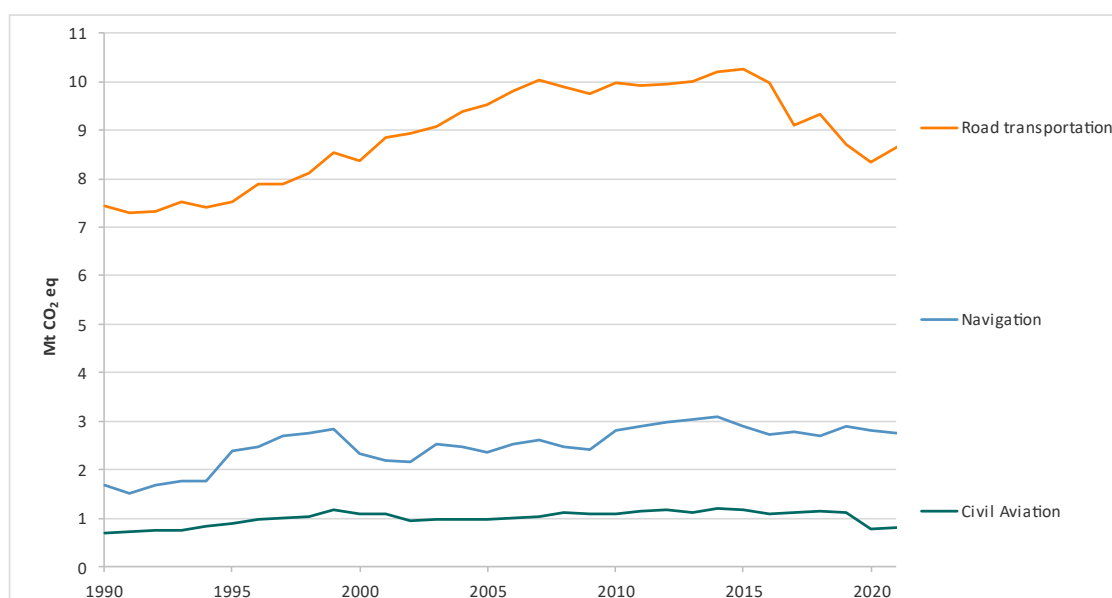


Figure 2-18. Emissions in million tonnes CO<sub>2</sub> equivalents from the most important modes of transport, 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

**Table 2.11 Total emissions of greenhouse gases from the transport sector in Norway, 1990-2021. Million tonnes CO<sub>2</sub> equivalents.**

| Year | Civil Aviation | Road transportation | Railways | Navigation | Total Transport |
|------|----------------|---------------------|----------|------------|-----------------|
| 1990 | 0.7            | 7.4                 | 0.1      | 1.7        | 9.9             |
| 1995 | 0.9            | 7.5                 | 0.1      | 2.4        | 10.9            |
| 2000 | 1.1            | 8.4                 | 0.1      | 2.3        | 11.9            |
| 2005 | 1.0            | 9.5                 | 0.1      | 2.4        | 12.9            |
| 2010 | 1.1            | 10.0                | 0.0      | 2.8        | 13.9            |
| 2011 | 1.1            | 9.9                 | 0.0      | 2.9        | 14.0            |
| 2012 | 1.2            | 9.9                 | 0.0      | 3.0        | 14.1            |
| 2013 | 1.1            | 10.0                | 0.0      | 3.0        | 14.2            |
| 2014 | 1.2            | 10.2                | 0.0      | 3.1        | 14.6            |
| 2015 | 1.2            | 10.2                | 0.1      | 2.9        | 14.3            |
| 2016 | 1.1            | 10.0                | 0.0      | 2.7        | 13.8            |
| 2017 | 1.1            | 9.1                 | 0.1      | 2.8        | 13.1            |
| 2018 | 1.2            | 9.3                 | 0.1      | 2.7        | 13.2            |
| 2019 | 1.1            | 8.7                 | 0.1      | 2.9        | 12.8            |
| 2020 | 0.8            | 8.3                 | 0.0      | 2.8        | 12.0            |
| 2021 | 0.8            | 8.7                 | 0.0      | 2.8        | 12.3            |

Source: Statistics Norway/Norwegian Environment Agency

The category Other fuel combustion (Table 2.10) includes, in particular, fuel combustion in agriculture, forestry and fisheries, residential sector and commercial/institutional sectors. The total emissions from this category were 3.2 million tonnes of CO<sub>2</sub> equivalents in 2021. Emissions decreased by 33.7 per cent from 1990 to 2021 but increased by 3.7 per cent from 2020 to 2021.

In 2021, GHG emissions from residential sources (stationary and mobile) accounted for 18.8 per cent of emissions from the “other fuel combustion” category. Emissions from the residential subsector have been reduced by 67.8 per cent since 1990.

Emissions from stationary combustion in the residential subsector are climate dependent. A mild winter can lead to relatively lower consumption of fuels and thus reduced emissions, whereas dry and cold winter can lead to relatively higher emissions. Between 1990 and 2021, emissions from stationary combustion in the residential sector have decreased by 83.4 per cent, mainly due to the electrification of heating infrastructure. Emissions from mobile combustion have increased by 8.3 per cent in the same period, due to increased activity.

Emissions from commercial/institutional sources (mobile and stationary) have decreased by 4.6 per cent since 1990. Emissions from commercial/institutional stationary sources decreased by 74.5 per cent from 1990 to 2021, whereas emissions from commercial/institutional mobile sources increased by 139.2 per cent between 1990 and 2021.

The sub-sector Fugitive emissions from fuels in Table 2.10 refers to emissions from oil and gas activities such as flaring of natural gas, leakages and venting of methane. Indirect CO<sub>2</sub> emissions from NMVOC emitted during the loading and unloading of oil tankers are also accounted for in this sub-sector. Fugitive emissions from fuels contributed to 4.3 per cent of the national GHG emissions in 2021 and to 6.3 per cent of the GHG emissions within the energy sector. Fugitive emissions from fuels have decreased by 29.7 per cent since 1990 with an increase of 8.0 per cent between 2020 and 2021.

Reduced emissions from flaring since 1990 are partly explained by the introduction of tax on gas flared offshore from 1991 and implemented technical measures. The amount of gas flared may fluctuate from year to year due to variation of start-ups, maintenance and interruption in operation.

### 2.3.2 Industrial processes and product use

The industrial processes and other product use (IPPU) sector accounted for 18.3 per cent of the national GHG emissions in 2021 (Figure 2-14). The emissions from this sector decreased by 38.7 per cent from 1990 to 2021 and increased by 0.1 per cent between 2020 and 2021.

Metal industry is the main source of emissions within the IPPU sector in the period 1990-2021. It contributed to 59.0 per cent of the GHG emissions from the IPPU sector in 2021. The other main contributing sources in 2021 were chemical industry, mineral industry and product uses as substitutes for ODS (ozone depleting substances). They contributed to 20.4 per cent, 10.4 per cent and 7.0 per cent of the GHG emissions from the IPPU sector, respectively.

Figure 2-19 shows the variations in the contribution to GHG emissions from 1990 to 2021 of the different IPPU categories. [Table 2.12](#) provides figures for the GHG emissions from the IPPU sector for the same period.

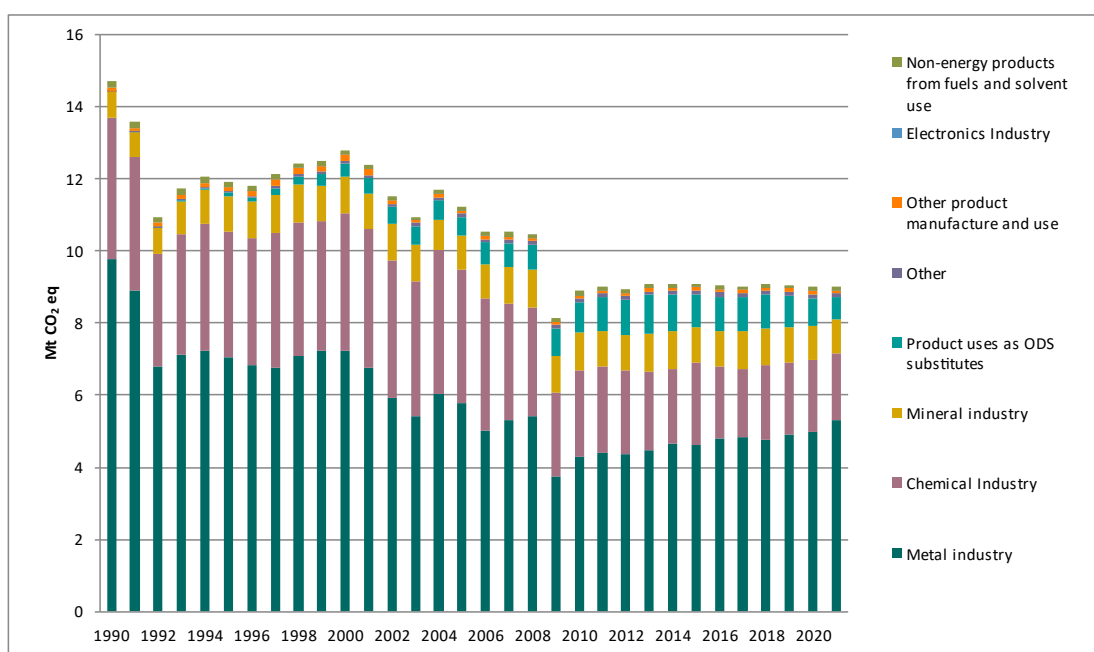


Figure 2-19. Total greenhouse gas emissions (Mtonnes CO<sub>2</sub> eq.) in the IPPU sub-sector in Norway, 1990-2021<sup>6</sup>. Source: Statistics Norway/Norwegian Environment Agency

During the first half of the 20th century, a large-scale industrialization took place in Norway. Many industrial communities appeared around the large hydroelectric resources, particularly in the western parts of the country. Typical products were raw materials and semi-manufactured goods such as aluminium and ferroalloys. The main energy source has always been hydroelectricity. However, fossil fuels have been used as reducing agents or raw materials. Greenhouse gases are then emitted as process related gases.

10.8 per cent of national GHG emissions came from the metal industry in the IPPU sector in 2021, whose emissions increased by 6.7 per cent from 2020 to 2021.

The largest contributors to the GHG emissions from metal production in 2021 are productions of ferroalloys and aluminium. Emissions from those productions constituted 97.4 per cent of emissions from the metal industry in 2021. The large decrease in emissions in 2009 reflects low production levels of ferroalloys, due to lower economic activity and economic recession.

<sup>6</sup> Under Other production, Norway reports the two source categories: pulp and paper and food and drink.



In 1990, PFC emissions from aluminium production contributed to 6.8 per cent of the national GHG emissions, while in 2021, it has been reduced to 0.5 per cent. Emissions of PFCs from aluminium production have decreased by 93.6 per cent since 1990 but increased by 53.5 per cent between 2020 and 2021. The increase in PFC emissions in 2021 is primarily due to increased production capacity at one of the plants. The production from this plant increased from about 94 kt aluminium in 2020 to about 169 kt aluminium in 2021.

Since 2010, production of ferroalloys has been the most important source of GHG emissions within the metal production category. The GHG emissions from ferroalloys production amounted to 2.8 million tonnes of CO<sub>2</sub> equivalents in 2021 and accounted for 5.7 per cent of the national total GHG emissions. Emissions from production of ferroalloys increased by 9.1 per cent from 1990 to 2021, with a 3.5 per cent increase from 2020. The large increase in emissions from 2009 to 2010 (50.2 per cent) is due to the low production level in 2009.

| Table 2.12 Total greenhouse gas emissions (Mtonnes CO <sub>2</sub> eq.) from the IPPU sub-sectors in Norway, 1990-2021. |                  |                   |                |                                                |                      |                                 |                                   |       |       |
|-------------------------------------------------------------------------------------------------------------------------|------------------|-------------------|----------------|------------------------------------------------|----------------------|---------------------------------|-----------------------------------|-------|-------|
| Year                                                                                                                    | Mineral industry | Chemical Industry | Metal industry | Non-energy products from fuels and solvent use | Electronics Industry | Product uses as ODS substitutes | Other product manufacture and use | Other | Total |
| 1990                                                                                                                    | 0.7              | 3.9               | 9.8            | 0.2                                            | -                    | 0.0                             | 0.1                               | 0.0   | 14.7  |
| 1995                                                                                                                    | 1.0              | 3.5               | 7.1            | 0.1                                            | 0.0                  | 0.1                             | 0.1                               | 0.0   | 11.9  |
| 2000                                                                                                                    | 1.0              | 3.8               | 7.2            | 0.1                                            | 0.0                  | 0.4                             | 0.2                               | 0.1   | 12.8  |
| 2005                                                                                                                    | 0.9              | 3.7               | 5.8            | 0.1                                            | 0.0                  | 0.5                             | 0.1                               | 0.1   | 11.2  |
| 2010                                                                                                                    | 1.0              | 2.4               | 4.3            | 0.1                                            | 0.0                  | 0.9                             | 0.1                               | 0.1   | 8.9   |
| 2011                                                                                                                    | 1.0              | 2.4               | 4.4            | 0.1                                            | 0.0                  | 0.9                             | 0.1                               | 0.1   | 9.0   |
| 2012                                                                                                                    | 1.0              | 2.3               | 4.4            | 0.1                                            | 0.0                  | 1.0                             | 0.1                               | 0.1   | 9.0   |
| 2013                                                                                                                    | 1.1              | 2.2               | 4.5            | 0.1                                            | 0.0                  | 1.1                             | 0.1                               | 0.1   | 9.1   |
| 2014                                                                                                                    | 1.1              | 2.1               | 4.6            | 0.1                                            | 0.0                  | 1.0                             | 0.1                               | 0.1   | 9.1   |
| 2015                                                                                                                    | 1.0              | 2.3               | 4.6            | 0.1                                            | 0.0                  | 0.9                             | 0.1                               | 0.1   | 9.1   |
| 2016                                                                                                                    | 1.0              | 2.0               | 4.8            | 0.1                                            | 0.0                  | 1.0                             | 0.1                               | 0.1   | 9.0   |
| 2017                                                                                                                    | 1.0              | 1.9               | 4.8            | 0.1                                            | 0.0                  | 1.0                             | 0.1                               | 0.1   | 9.0   |
| 2018                                                                                                                    | 1.0              | 2.1               | 4.8            | 0.1                                            | 0.0                  | 0.9                             | 0.1                               | 0.1   | 9.1   |
| 2019                                                                                                                    | 1.0              | 2.0               | 4.9            | 0.1                                            | 0.0                  | 0.9                             | 0.1                               | 0.1   | 9.1   |
| 2020                                                                                                                    | 1.0              | 2.0               | 5.0            | 0.1                                            | 0.0                  | 0.7                             | 0.1                               | 0.1   | 9.0   |
| 2021                                                                                                                    | 0.9              | 1.8               | 5.3            | 0.1                                            | 0.0                  | 0.6                             | 0.1                               | 0.1   | 9.0   |

Source: Statistics Norway/Norwegian Environment Agency

In 1990, SF<sub>6</sub> from magnesium foundries accounted for 4.1 per cent of the national total GHG emissions. Emissions decreased until the closure of all plants in 2007. Reductions in

SF<sub>6</sub> emissions over the period are, in the early 90s, mainly due to improvements in the production processes, in 2002, due to the closing down of production of cast magnesium and in 2006, due to the closing down of secondary magnesium production.

The chemical industry includes primarily N<sub>2</sub>O from nitric acid production and CO<sub>2</sub> from production of ammonia and carbides. The GHG emissions from this sub-sector amounted to 1.8 million tonnes of CO<sub>2</sub> equivalents in 2021, which represented 3.7 per cent of the national GHG emissions. Emissions have decreased by 52.8 per cent since 1990, mainly due to the reduction of emissions from the production of nitric acid, ammonia, and carbides. Emissions have decreased by 7.5 per cent from 2020 to 2021.

The emissions from mineral industry were 0.9 million tonnes in 2021, which accounted for 1.9 per cent of the national GHG emissions. Emissions increased by 28.6 per cent from 1990 to 2021, mainly due to the increase of cement and lime production. The emissions from the mineral industry decreased by 2.9 per cent from 2020 to 2021.

In 2021, the CO<sub>2</sub> process emissions from cement production were 1.4 per cent of the national GHG emissions. They have increased by 10.1 per cent since 1990, due to increased production of clinker, with a decrease of 3.6 per cent from 2020 to 2021.

The total emissions from HFCs used as substitutes for ozone depleting substances amounted to 0.6 million tonnes of CO<sub>2</sub> equivalents in 2021. The emissions in 1990 were insignificant (49 tonnes CO<sub>2</sub> equivalents) but have increased substantially over the years. The emissions decreased by 16.2 per cent from 2020 to 2021. The application category refrigeration and air conditioning contribute by far to the largest part of the HFCs emissions. The other categories foam/foam blowing, and fire extinguishing contributes to relatively small amounts to the overall emissions. For more explanation on HFC emissions trends and sources, see 2.2.6.

### 2.3.3 Agriculture

In 2021, 9.6 per cent of the national GHG emissions originated from agriculture, corresponding to 4.7 million tonnes of CO<sub>2</sub> equivalents. Emissions from agriculture have decreased by 5.0 per cent since 1990 but increased by 1.1 per cent since 2020.

The largest sources of GHGs within the agriculture sector are enteric fermentation (CH<sub>4</sub>) and agricultural soils (N<sub>2</sub>O). In 2021, these categories represented 54.4 per cent and 31.2

per cent of the emissions from the agriculture sector, respectively, while manure management represented 11.7 per cent.

The main driver behind the emission trend in agriculture is the development of the number of animals in the dominant animal groups. Important reasons for the decreasing trend in GHG emissions are use of more concentrate and more effective milk production, which have led to a reduction of the number of dairy cows. For beef cows there has instead been an increase in the animal numbers since 1990.

Enteric fermentation contributed to 2.6 million tonnes CO<sub>2</sub> equivalents in 2021, corresponding to 5.2 per cent of the national GHG emissions. This category constituted 86.2 per cent of the overall CH<sub>4</sub> emissions from agriculture in 2021.

The emissions of N<sub>2</sub>O from agricultural soils amounted to 1.5 million tonnes CO<sub>2</sub> equivalents in 2021. This accounted for 71.0 per cent of the national N<sub>2</sub>O emissions in 2021, and 3.0 per cent of the national GHG emissions.

In 2021, emissions of CH<sub>4</sub> from manure management amounted to 0.4 million tonnes CO<sub>2</sub> equivalents and emissions of N<sub>2</sub>O from manure management amounted to 0.15 million tonnes CO<sub>2</sub> equivalents. Together this accounted for 1.1 per cent of the Norwegian GHG emissions.

Liming of agricultural soils and lakes is a source of emissions of CO<sub>2</sub> and corresponded to 2.6 per cent of the agricultural GHG emissions in 2021. These emissions have decreased with 47.4 per cent since 1990, mainly because less liming occurs on agricultural lands.

**Table 2.13 Greenhouse gas emissions (Mtonnes CO<sub>2</sub> eq.) from the agricultural sub-sectors in Norway, 1990-2021. Urea application is in ktonnes CO<sub>2</sub> eq.**

| Year | Enteric Fermentation | Manure Management | Agricultural Soils | Field burning of agricultural residues | Liming | Urea application (kt) | Total |
|------|----------------------|-------------------|--------------------|----------------------------------------|--------|-----------------------|-------|
| 1990 | 2.7                  | 0.5               | 1.5                | 0.0                                    | 0.2    | 0.6                   | 4.9   |
| 1995 | 2.7                  | 0.5               | 1.4                | 0.0                                    | 0.2    | 0.6                   | 4.9   |
| 2000 | 2.6                  | 0.5               | 1.4                | 0.0                                    | 0.1    | 0.1                   | 4.7   |
| 2005 | 2.6                  | 0.5               | 1.4                | 0.0                                    | 0.1    | 0.1                   | 4.7   |
| 2010 | 2.5                  | 0.6               | 1.3                | 0.0                                    | 0.1    | 0.3                   | 4.5   |
| 2011 | 2.5                  | 0.5               | 1.4                | 0.0                                    | 0.1    | 0.3                   | 4.5   |
| 2012 | 2.5                  | 0.5               | 1.4                | 0.0                                    | 0.1    | 0.2                   | 4.5   |
| 2013 | 2.5                  | 0.6               | 1.4                | 0.0                                    | 0.1    | 0.2                   | 4.5   |
| 2014 | 2.5                  | 0.6               | 1.4                | 0.0                                    | 0.1    | 0.2                   | 4.6   |
| 2015 | 2.6                  | 0.6               | 1.4                | 0.0                                    | 0.1    | 0.2                   | 4.7   |
| 2016 | 2.6                  | 0.6               | 1.4                | 0.0                                    | 0.1    | 0.2                   | 4.7   |
| 2017 | 2.6                  | 0.6               | 1.4                | 0.0                                    | 0.1    | 0.1                   | 4.7   |
| 2018 | 2.6                  | 0.6               | 1.4                | 0.0                                    | 0.1    | 0.1                   | 4.7   |
| 2019 | 2.5                  | 0.5               | 1.5                | 0.0                                    | 0.1    | 0.1                   | 4.6   |
| 2020 | 2.5                  | 0.5               | 1.5                | 0.0                                    | 0.1    | 0.1                   | 4.6   |
| 2021 | 2.6                  | 0.6               | 1.5                | 0.0                                    | 0.1    | 0.1                   | 4.7   |

Source: Statistics Norway/Norwegian Environment Agency

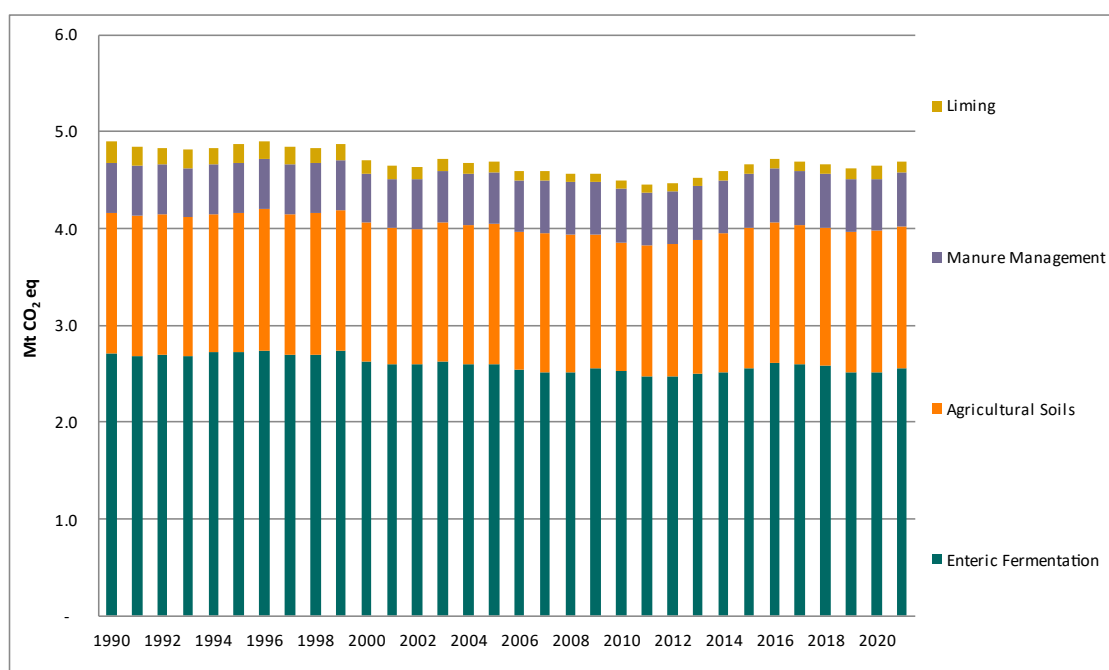


Figure 2-20. Total greenhouse gas emissions (Mtonnes CO<sub>2</sub> eq.) in the agriculture sub-sectors in Norway, 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

### 2.3.4 Land Use, Land-Use Change and Forestry (LULUCF)

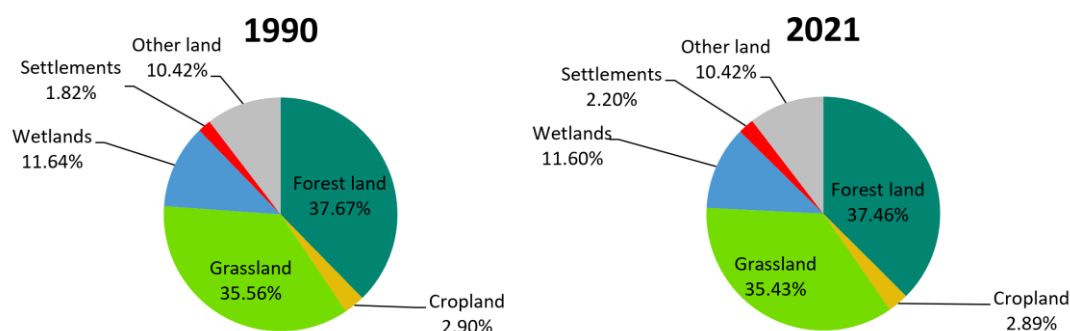
The LULUCF sector can function as both a source of atmospheric emissions and a sink of emissions through the removal of atmospheric CO<sub>2</sub>. The balance of the two is net emissions or removals in the LULUCF sector.

In 2021, the net removal in the LULUCF sector was 15.5 million tonnes CO<sub>2</sub> equivalents, which corresponds to about 32 per cent of the national GHG emissions (from all other sectors than LULUCF) that year. The average annual net sequestration from the LULUCF sector has been 17.7 million tonnes CO<sub>2</sub> equivalents per year for the period 1990-2020.

The calculated changes in carbon depend upon several factors such as growing conditions, harvest levels, management practices and land use changes.

The area distribution of the land-use categories for Norway in 1990 and 2021 is illustrated in Figure 2-21. The figure shows that the net changes in land-area distribution in Norway from 1990 to 2021 have been relatively small compared to the total area. Details on gross

changes between the respective categories may be found in the land-use change matrix in chapter 6.



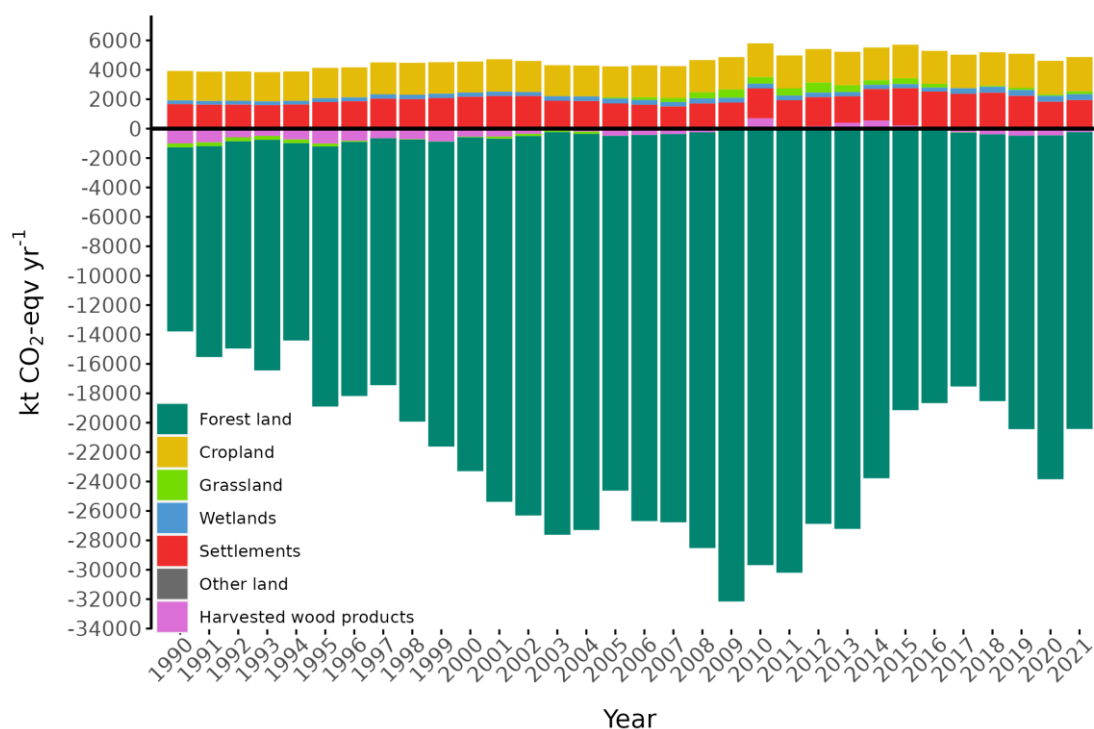
*Figure 2-21 Area (%) distribution between the IPCC land-use categories, 1990 and 2021. Source: The Norwegian Institute of Bioeconomy Research*

Figure 2-22 illustrates net emissions and removals of CO<sub>2</sub> equivalents by land-use category. As can be seen, all land-use categories other than forest land and harvested wood products had net emissions in 2021. In total, the emissions were calculated to about 4.9 million tonnes of CO<sub>2</sub> equivalents, of which the main emissions came from cropland and settlements.

Forest land was the major contributor to the net sequestration of CO<sub>2</sub> in the sector. In 2021, the total net removals from forest land were 20.2 million tonnes of CO<sub>2</sub>. Within this category, land converted to forest land contributed with 1.1 million tonnes of CO<sub>2</sub>.

Forest land is the land-use category responsible for the largest annual variations in CO<sub>2</sub> removals. The increase in living carbon stocks is result of an active forest management policy implemented over the last 60–70 years, which has led to an increase in the area of productive forest, as well as higher productivity in already existing forests. In addition, annual felling has been lower than annual increment. However, a large proportion of these forests are beginning to mature and hence reduce increment and leading to a future decline that is already apparent in the data. Croplands followed closely by settlements are

the land-use categories that are responsible for the largest net emissions of the six land use categories in the LULUCF sector in 2021.



*Figure 2-22 Net CO<sub>2</sub> emissions and removals (kt CO<sub>2</sub> equivalents per year) from the LULUCF sector by land-use category from 1990 to 2021, including emissions of N<sub>2</sub>O and CH<sub>4</sub>. Negative values are net removals, positive values are net emissions. Source: Norwegian Institute of Bioeconomy Research*

### 2.3.5 Waste

The waste sector, with emissions of 1.4 million tonnes of CO<sub>2</sub> equivalents in 2021, accounted for 2.9 per cent of the national GHG emissions. This sector includes emissions from landfills (CH<sub>4</sub>), wastewater handling (CH<sub>4</sub> and N<sub>2</sub>O), biological treatment of solid waste and small-scale waste incineration (CO<sub>2</sub> and CH<sub>4</sub>). Waste incineration with utilization of energy is included in the Energy sector.

Solid waste disposal on land (landfills) is the main source category within the waste sector. It accounted for 63.9 per cent of the sector's total emissions in 2021. Wastewater handling



accounted for 18.7 per cent, waste incineration for 12.4 per cent, and biological treatment of solid waste accounted for 4.9 per cent.

GHG emissions from the waste sector have generally decreased since 1990. The distribution of the waste emissions by category is presented in Figure 2-23 and [Table 2.14](#).

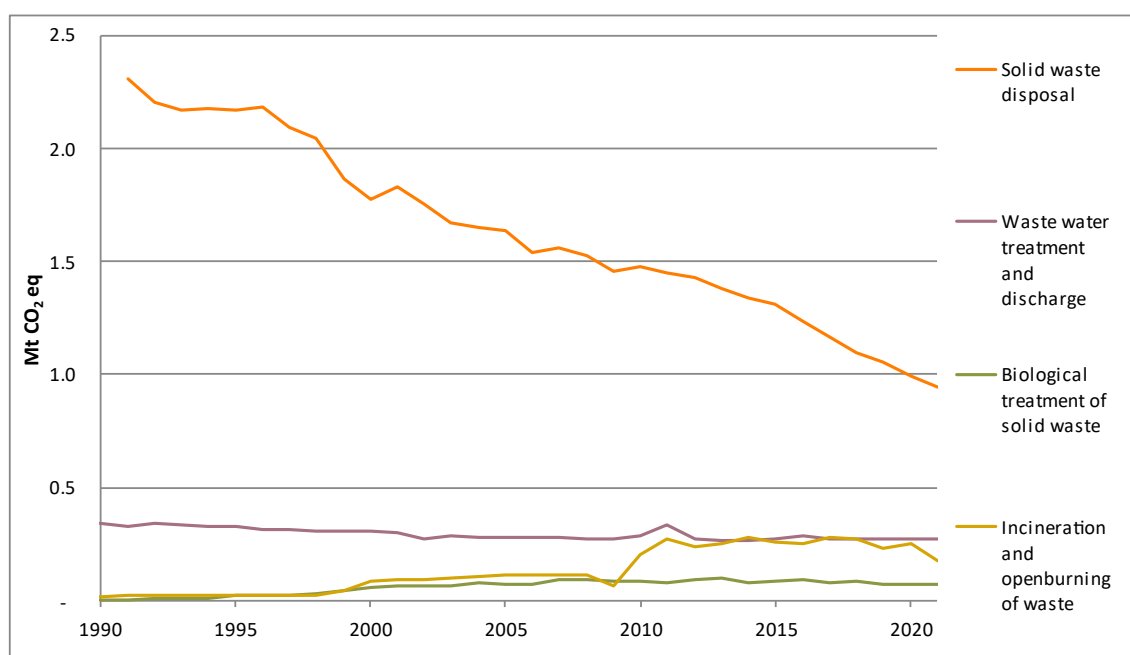


Figure 2-23 Total emissions of greenhouse gases (Mtonnes CO<sub>2</sub> eq.) in Norway from the waste categories, 1990-2021. Source: Statistics Norway/Norwegian Environment Agency

| <b>Table 2.14 Emissions (Mtonnes CO<sub>2</sub> eq.) from the waste sub-sectors in Norway, 1990-2021. Incineration and open burning of waste is presented in ktonnes CO<sub>2</sub> eq.</b> |                      |                                     |                                        |                                    |       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-------------------------------------|----------------------------------------|------------------------------------|-------|
| Year                                                                                                                                                                                        | Solid waste disposal | Biological treatment of solid waste | Incineration and open burning of waste | Wastewater treatment and discharge | Total |
| 1990                                                                                                                                                                                        | 2.3                  | 0.0                                 | 0.0                                    | 0.3                                | 2.7   |
| 1995                                                                                                                                                                                        | 2.2                  | 0.0                                 | 0.0                                    | 0.3                                | 2.6   |
| 2000                                                                                                                                                                                        | 1.8                  | 0.1                                 | 0.1                                    | 0.3                                | 2.3   |
| 2005                                                                                                                                                                                        | 1.5                  | 0.1                                 | 0.1                                    | 0.3                                | 2.0   |
| 2010                                                                                                                                                                                        | 1.4                  | 0.1                                 | 0.2                                    | 0.3                                | 2.0   |
| 2011                                                                                                                                                                                        | 1.4                  | 0.1                                 | 0.3                                    | 0.3                                | 2.1   |
| 2012                                                                                                                                                                                        | 1.4                  | 0.1                                 | 0.2                                    | 0.3                                | 2.0   |
| 2013                                                                                                                                                                                        | 1.3                  | 0.1                                 | 0.3                                    | 0.3                                | 2.0   |
| 2014                                                                                                                                                                                        | 1.3                  | 0.1                                 | 0.3                                    | 0.3                                | 1.9   |
| 2015                                                                                                                                                                                        | 1.2                  | 0.1                                 | 0.3                                    | 0.3                                | 1.9   |
| 2016                                                                                                                                                                                        | 1.2                  | 0.1                                 | 0.3                                    | 0.3                                | 1.8   |
| 2017                                                                                                                                                                                        | 1.1                  | 0.1                                 | 0.3                                    | 0.3                                | 1.7   |
| 2018                                                                                                                                                                                        | 1.1                  | 0.1                                 | 0.3                                    | 0.3                                | 1.7   |
| 2019                                                                                                                                                                                        | 1.0                  | 0.1                                 | 0.2                                    | 0.3                                | 1.6   |
| 2020                                                                                                                                                                                        | 0.9                  | 0.1                                 | 0.3                                    | 0.3                                | 1.5   |
| 2021                                                                                                                                                                                        | 0.9                  | 0.1                                 | 0.2                                    | 0.3                                | 1.4   |

Source: Statistics Norway/Norwegian Environment Agency

In 2021, emissions were 45.9 per cent lower than in 1990 and 6.3 per cent lower than in 2020. Methane emissions from solid waste disposal (landfills) decreased by 60.0 per cent since 1990.

The total amount of waste generated increased by more than 63 per cent from 1995 to 2021, but due to the increase in material recycling and a ban against disposing biodegradable waste to landfills, methane emissions have decreased, leading to a decrease in total emissions of greenhouse gases from the waste sector. From 2002 landfilling of easy degradable organic waste was prohibited. This prohibition was replaced by the wider prohibition of depositing from 2009 that applies to all biodegradable waste.

## 2.4 Emission trends for indirect greenhouse gases and SO<sub>2</sub>

Nitrogen oxides (NO<sub>x</sub>), non-methane volatile organic compounds (NMVOC) and carbon monoxide (CO) are not greenhouse gases but have an indirect effect on the climate

through their influence on greenhouse gases and in particular ozone. Sulphur dioxide (SO<sub>2</sub>) also has an indirect impact on climate, as it increases the level of aerosols with a subsequent cooling effect. Therefore, emission trends of these gases are to some extent included in the inventory.

The overall NO<sub>x</sub> emissions decreased with approximately 27.8 per cent from 1990 to 2021. This can primarily be explained by stricter emission regulations for road traffic, which has led to a 59.8 per cent and 44.8 per cent reduction of NO<sub>x</sub> emissions from road transport and overall transport, respectively, since 1990. These reductions counteracted increasing emissions from e.g., oil and gas production. From 2020 to 2021, the total NO<sub>x</sub> emissions decreased by 3.5 per cent.

There was an increase in NMVOC emissions in the period from 1990 to 2001, mainly because of the rise in oil production. However, NMVOC emissions decreased by 65.6 per cent from 2001 to 2021 and were in 2021 55.2 per cent lower than in 1990. This reduction has been achieved through the implementation of measures to increase the recycling of oil vapour at loading and storage units in the oil and gas industry. From 2020 to 2021, the emissions of NMVOC decreased by 3.7 per cent.

CO emissions have decreased by 46.0 per cent over the period 1990-2021. This is explained primarily by the implementation of new emission standards for motor vehicles.

SO<sub>2</sub> emissions were reduced by 70.2 per cent from 1990 to 2021. This can mainly be explained by a reduction in sulphur content of all oil products and lower process emissions from ferroalloys and aluminium productions as well as refineries.

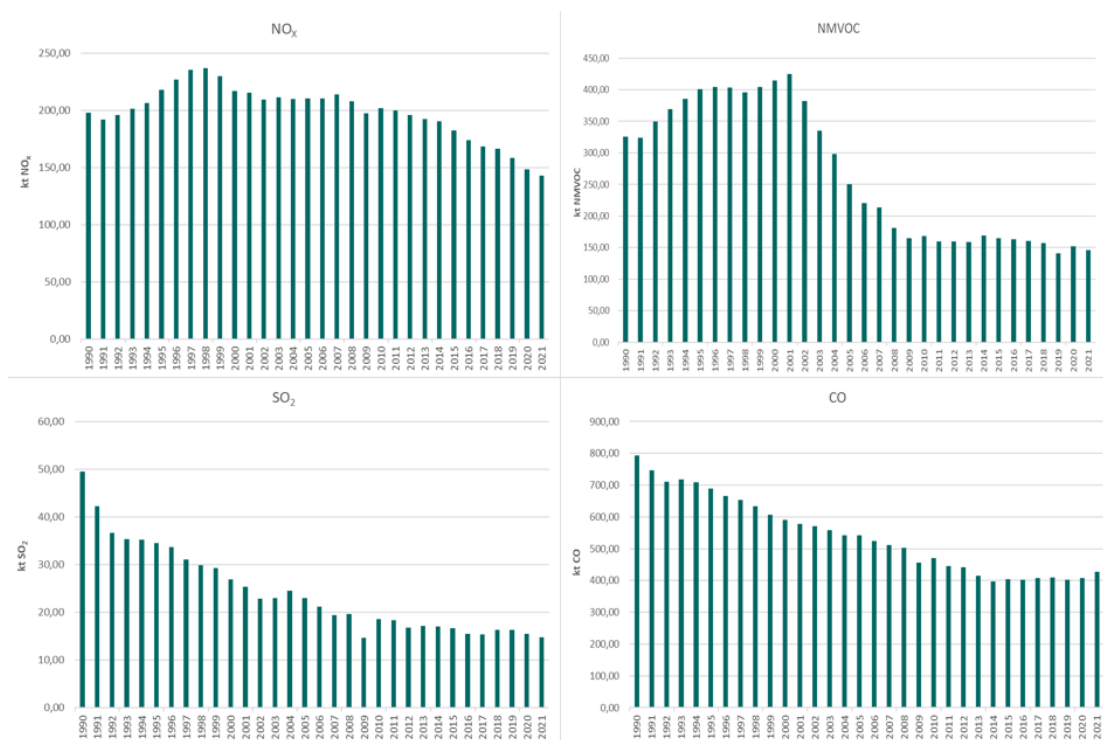


Figure 2-24. Emissions (ktonnes) of NO<sub>x</sub>, NMVOC, SO<sub>2</sub>, and CO in Norway, 1990-2021. Source: Statistics Norway/ Norwegian Environment Agency

## 3. Energy (CRF sector 1)

### 3.1 Overview of sector

#### 3.1.1 Sources and trends

The Energy sector, including fugitive emissions, accounted for nearly 70 per cent of the Norwegian greenhouse gas emissions in 2021. In 1990, the Energy sector's share of the total greenhouse gas emissions was 56 per cent.

Road traffic and offshore gas turbines (electricity generation and pumping of natural gas in pipelines) are the sector's largest single contributors to the sector's emissions and the latter is the sector that has increased the most since 1990. Other important sources in the Energy sector are coastal navigation, manufacturing, as well as oil and gas operations, which also give rise to significant amounts of fugitive emissions.

GHG emissions in the Energy sector have increased by 19 per cent from 1990 to 2021 (Figure 3-2), primarily due to increased activity in the sectors of oil and gas extraction and transport, specifically road transport. The emissions generally increased over 20 years to a peak in 2010, when emissions were 39 per cent higher than in 1990. During the period of increase, there were temporary emission reductions in the sector. Among these temporary reductions is the decrease from 2007 to 2008, that was mainly caused by start-up problems at a new gas terminal. This caused larger than normal emissions the first years, and later reductions in emissions as it was fully operational in 2009. The financial crisis also contributed to lower emissions in 2009. However, the start-up of a gas fired power plant balanced the reduction so total emissions from energy were flat in 2009.

The emission reduction from 2010 to 2012 was mainly due to close-down of the gas power plant that started in 2009, as well as a broad reduction of fuel oil in residential and commercial heating. Increased emissions from oil and gas extraction contributed to a new peak in 2015.

Since 2015, emissions have decreased by 13 per cent. The reduction is mainly due to reduced emissions from oil and gas extraction, including flaring, and transport, particularly road transport. Temporarily reduced activity at an oil refinery reduced fugitive emissions in 2019 and 2020. In 2021 emissions continued to decrease. One important reason was a temporary shutdown of an LNG plant, which in years of normal operation reports emissions of around 1 million tonnes CO<sub>2</sub>.

Total sales of gasoline and autodiesel including biofuels reached a peak in 2016 and has since decreased by 10 per cent in volume terms, partly due to an increased share of battery electric vehicles. The use of biofuels increased to a peak in 2017 and has since then varied between 11 and 14 per cent of total road fuels by volume. The biofuel fraction in 2021 was 14 per cent.

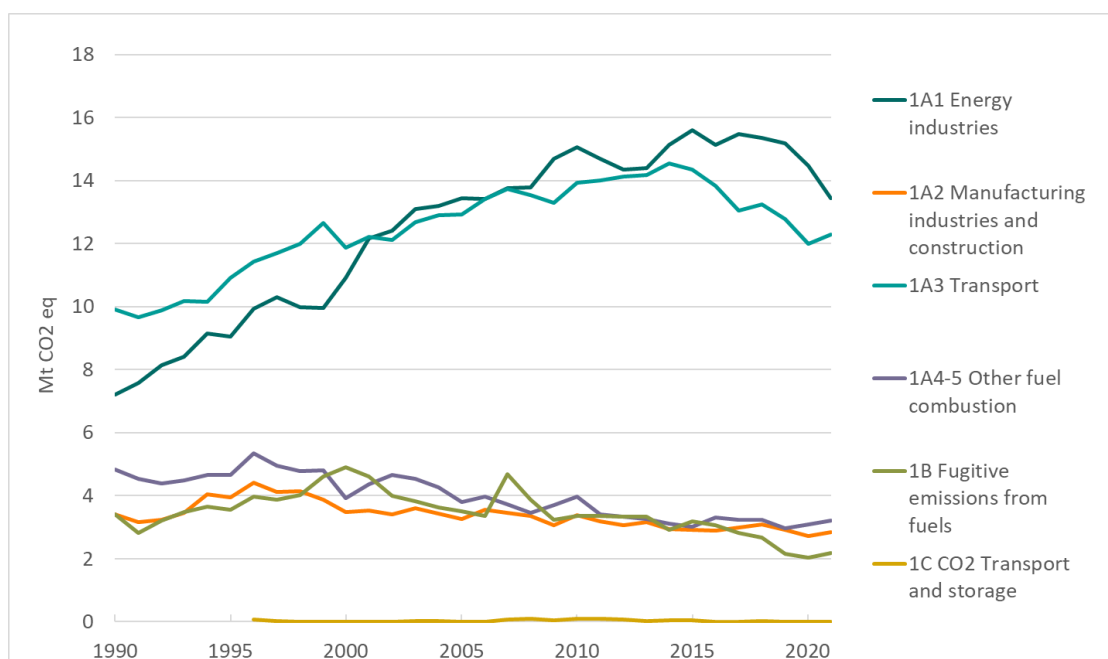
The covid-19 pandemic contributed to reduced emissions in both 2020 and 2021, mainly in air and road transport. Fuel consumption in domestic civil air transport was reduced by 30 per cent from 2019 to 2020 and by 28 per cent between 2019 and 2021. Road traffic fuel consumption was reduced by 7 per cent between 2019 and 2020. Road traffic did however increase in 2021, to pre-pandemic levels. Reduced emissions from oil and gas extraction also contributed to the overall trend in 2020 and 2021.

Figure 3-1 and Figure 3-2 show the trend and the relative changes to 1990, in GHG emissions for the different Energy sectors. The main emitting sectors are the energy industries sector (combustion in oil and gas production, refineries, electricity production and district heating) and the transport sector (civil aviation, road transportation, railways, navigation). Both sectors have increased since 1990, especially the energy industries sector, which has almost doubled since 1990.

Emissions from the manufacturing industries and construction sector, the other fuel combustion sector<sup>7</sup> and the fugitive emissions from fuel sector have all decreased between 1990 and 2021.

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<sup>7</sup> "Other fuel combustion sector" includes both the sectors Other Combustion (CRF 1A4) and Other (CRF 1A5)



*Figure 3-1: Greenhouse gas emissions from energy sectors and fugitive emissions. 1990-2021. Million tonne CO<sub>2</sub> equivalents. Source: Statistics Norway/Norwegian Environment Agency*

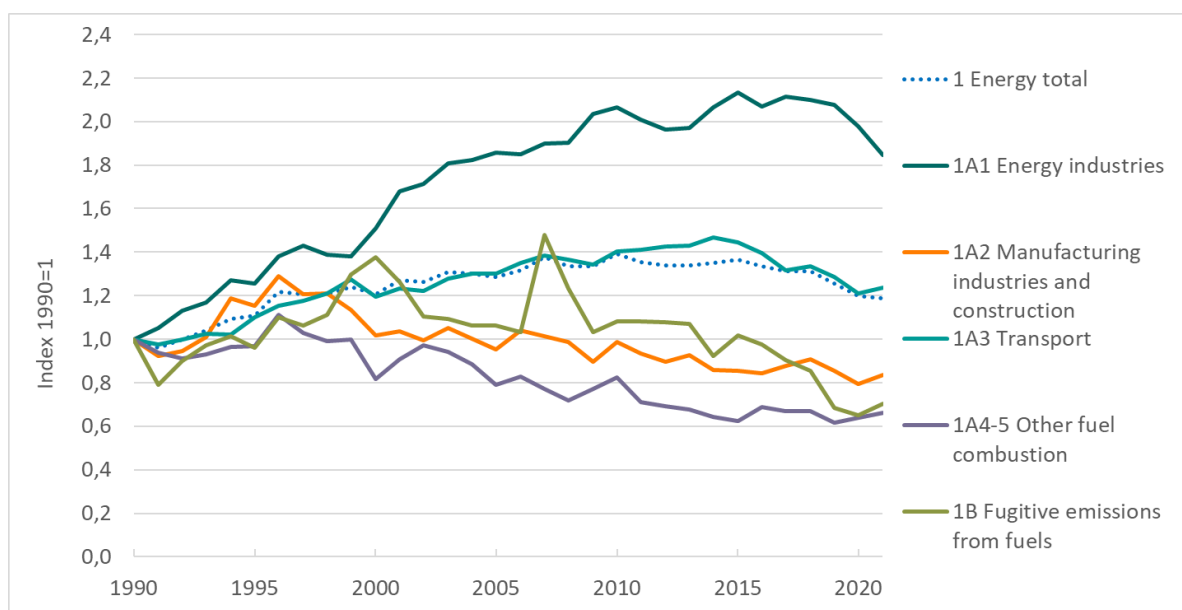
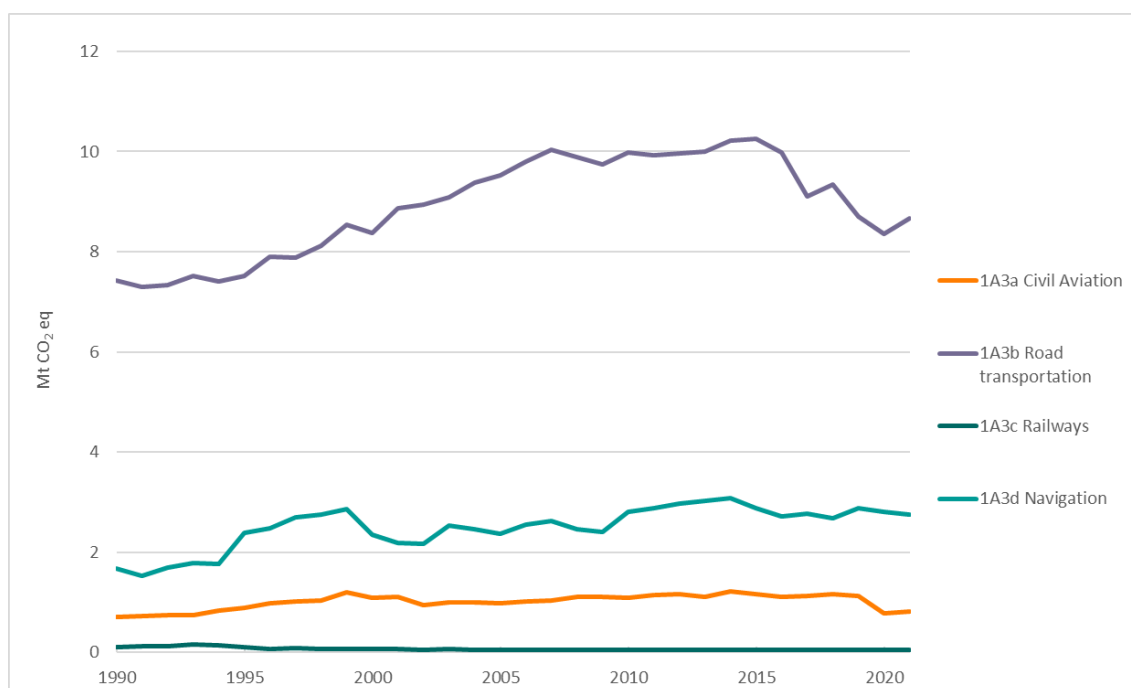


Figure 3-2: Relative changes to 1990 in GHG emissions for energy combustion. 1990-2021. Index 1990=1. Source: Statistics Norway/Norwegian Environment Agency

The following figures give an overview over trends in the transport sectors. In 2021, the total GHG emissions in the transport sector was 12.3 million tonnes CO<sub>2</sub> equivalents of which road transportation contributed to 71 per cent, navigation to 22 per cent, civil aviation to 7 per cent and railways to less than 1 per cent.

Figure 3-3 and Figure 3-4 show the trend and the relative changes of transport emissions from 1990 to 2021. They show that emissions from road transportation, navigation and aviation have increased during the period, while emissions from railways have decreased. Since 1990, emissions from civil aviation have increased by 16 per cent, navigation by 64 per cent and road transportation by 17 per cent. Emissions from road transport have decreased significantly since 2015, mainly due to use of biofuels. Emissions from railways have decreased by 56 per cent compared with 1990. Emissions from road traffic and in particular aviation dropped sharply in 2020 due to the covid-19 pandemic, however road traffic has increased by 3.7 per cent between 2020 and 2021.





*Figure 3-3: Greenhouse gas emissions from the most important transport sectors. 1990-2021. Million tonnes CO<sub>2</sub> equivalents. Source: Statistics Norway/ Norwegian Environment Agency*

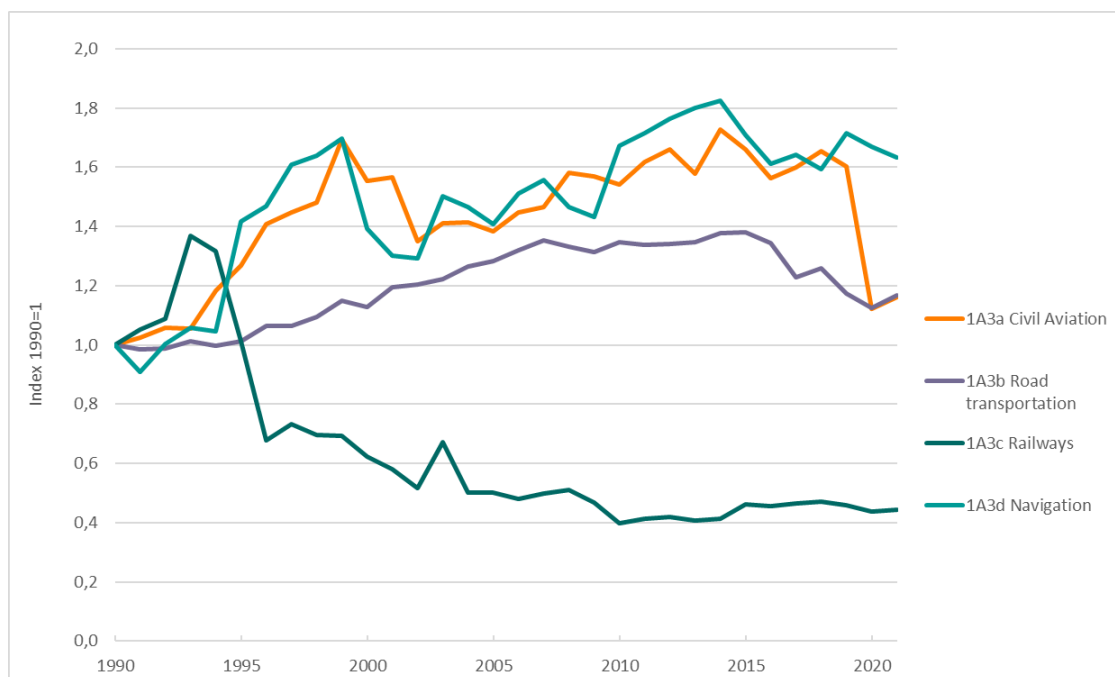


Figure 3-4: Relative changes to 1990 in GHG emissions for the most important transport sectors. Civil aviation, road transportation, navigation, and other transportation. Index 1990=1.

### 3.1.2 Key source categories

Section 1.5 describes the overall results of the approach 2 key category analysis performed for the years 1990 and 2021. [Table 3.1](#) gives the key categories in the energy sector in terms of total level and/or trend uncertainty for 1990 and/or latest submission year in CRF order.

| <b>Table 3.1 Key categories in the Energy sector.</b> |                                                              |                 |                                           |               |
|-------------------------------------------------------|--------------------------------------------------------------|-----------------|-------------------------------------------|---------------|
| <b>CRF code</b>                                       | <b>Source Category</b>                                       | <b>Gas</b>      | <b>Key category according to approach</b> | <b>Method</b> |
| <b>1A1,1A2,1A4</b>                                    | Fuel Combustion Activities (Sectoral Approach) Biomass       | CH <sub>4</sub> | 2                                         | Tier 2        |
| <b>1A1,1A2,1A4</b>                                    | Fuel Combustion Activities (Sectoral Approach) Gaseous Fuels | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A1,1A2,1A4</b>                                    | Fuel Combustion Activities (Sectoral Approach) Gaseous Fuels | CH <sub>4</sub> | 2                                         | Tier 2        |
| <b>1A1,1A2,1A4</b>                                    | Fuel Combustion Activities (Sectoral Approach) Liquid Fuels  | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A1,1A2,1A4</b>                                    | Fuel Combustion Activities (Sectoral Approach) Other Fuels   | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A1,1A2,1A4</b>                                    | Fuel Combustion Activities (Sectoral Approach) Solid Fuels   | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A3A</b>                                           | Civil Aviation                                               | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A3B</b>                                           | Road Transportation                                          | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A3D</b>                                           | Navigation                                                   | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A3d</b>                                           | Navigation                                                   | CH <sub>4</sub> | 2                                         | Tier 2        |
| <b>1A4</b>                                            | Other sectors                                                | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1A5B</b>                                           | Mobile                                                       | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1B1a</b>                                           | Coal Mining                                                  | CH <sub>4</sub> | 2                                         | Tier 1        |
| <b>1B2A</b>                                           | Oil (incl. oil refineries, gasoline distribution)            | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1B2C</b>                                           | Venting and Flaring                                          | CO <sub>2</sub> | 2                                         | Tier 2        |
| <b>1B2a</b>                                           | Oil (incl. oil refineries, gasoline distribution)            | CH <sub>4</sub> | 2                                         | Tier 2        |
| <b>1B2b</b>                                           | Natural Gas                                                  | CH <sub>4</sub> | 2                                         | Tier 2        |
| <b>1B2c</b>                                           | Venting and Flaring                                          | CH <sub>4</sub> | 2                                         | Tier 2        |
| <b>1C</b>                                             | CO <sub>2</sub> transport and storage                        | CO <sub>2</sub> | Qualitative                               | Tier 3        |

Source: Statistics Norway/Norwegian Environment Agency

An important issue, which is also elaborated in this sector, concerns the capture, transport, and storage of CO<sub>2</sub> from natural gas produced at the gas-condensate field Sleipner Vest, including gas from the Gudrun field, and the gas field Snøhvit. These unique operations are discussed in detail in section 3.5.

### 3.1.3 Emission allocation

Generally, energy combustion for energy purposes is reported in 1.A Fuel Combustion Activities, while flaring and other fugitive emissions are reported in 1.B Fugitive Emissions

from Fuels. Emissions from waste incineration at district heating plants are accounted for under the energy sector, as the energy is utilized. Methane from landfills and other biogas used for energy purposes is also accounted for in this sector. Emissions from flaring in the energy sectors are reported in 1.B.2c Flaring and described in section 3.4, as this energy combustion is not for energy purposes. Emissions from burn off of coke at catalysts in refineries are reported in 1.B.2.a iv for the same reason as for flaring.

Some emissions from energy products and combustion are reported in other sectors than 1 Energy. For plants that use coal and coke as reducing agents are accounted for in sector 2 IPPU (chapter 4). The same applies to fuels and feedstocks used in ammonia production and petrochemical industry, except for minor emissions from the combustion of diesel and propane, which are reported under 1A2C. Flaring in manufacturing industries is also reported in 2 IPPU. Flaring of landfill gas and other biogas is reported in sector 5 Waste (chapter 7). The same applies to emissions from accidental fires, etc. Emissions from burning of crop residues and agricultural waste are accounted for in sector 3 Agriculture (chapter 5).

A more detailed description of the delimitation of energy combustion is given in section 3.2.1.1.

### **3.1.4 Mode of presentation**

The elaboration of the energy sector in the following starts with a general description of emissions from the energy combustion sources (section 3.2). Then followed by a description of fugitive emissions (sections 3.3 and 3.4) and a discussion on the capture, transport, and storage of CO<sub>2</sub> from natural gas produced at the gas-condensate field Sleipner Vest, including gas from the Gudrun field, and the gas field Snøhvit (section 3.5). Cross-cutting issues are elaborated in section 3.6 and comprise the following elements:

- Comparison between the sectoral and reference approach
- Feedstock and non-energy use of fuels

Finally, the memo items of international bunker fuels and CO<sub>2</sub> emissions from biomass are addressed in section 3.7.

Indirect CO<sub>2</sub> emissions from CH<sub>4</sub> and NMVOC (from energy as well as other sources) are addressed in chapter 9.

In the case of energy combustion, emissions from the individual combustion sources are discussed after a comprehensive presentation of the energy combustion sector as a whole

(section 3.2). The purpose for such an arrangement is to avoid repetition of methodological issues which are common among underlying source categories, and to enable easier cross-reference.

## 3.2 Fuel Combustion

### 3.2.1 Overview

This section describes the general methodology for calculation of GHG emissions from the combustion of fossil fuels and biomass. All known combustion activities within energy utilisation in various industries and private households are included.

The GHG emissions from fuel combustion (1A) accounted for 65 per cent of national total emissions in 2021, and more than 90 per cent of the total emissions from the energy sector. The emissions increased by 25 per cent between 1990 and 2021. The increase is primarily due to activity growth in oil and gas extraction, which comprises the major part of the energy industries sector, and in transport, mainly road transport.

The fuel combustion sector is dominated by emissions of CO<sub>2</sub>, which in 2021 contributed 98 per cent to the totals of this sector (CRF 1A).

This sector hosts several source categories defined as key according to approach 2 and approach 1 key category analyses (Table 3.1). Along with the non-key categories, they are presented in detail in the following sections.

Table 3.3 presents the shares of estimated and reported emissions used in the inventory for the different sectors and for the different greenhouse gases in 2021. It shows that a large share of GHG emissions from Energy industries and Manufacturing Industries and Construction included in the Norwegian GHG Inventory are taken from annual reports sent by each plant to the Norwegian Environment Agency. Such annual reports are:

- reports as required by their regular permit
- reports as required by the permit under the EU emission trading system (EU ETS)
- reports as required by a voluntary agreement

Annex VII QA/QC of point sources includes references to documents that in detail describe requirements for measuring and reporting, specifically for the EU ETS and the voluntary agreement.

### 3.2.1.1 Methodological issues

Emissions from fuel combustion are estimated at the sectoral level in accordance with the IPCC sectoral approach Tier 1/Tier 2/Tier 3. Total fuel consumption is, in many cases, more reliable than the breakdown to sectoral consumption.

The general methodology for estimating emissions from fuel combustion is multiplication of fuel consumption by source and sector by an appropriate emission factor, as shows in equation o. Exceptions are road traffic and aviation, where more detailed estimation models are used; involving additional activity data (see sections 3.2.5 and 3.2.4, respectively). The total amounts of fuel consumption are taken from the Norwegian energy balance (see Annex III).

The mean theoretical energy content of fuels and their density are listed in [Table 3.2](#). Note that the data from the energy balance used in the emission inventory are in mass (or volume) terms. The energy contents in the table are not used in emission calculations. They are used in providing the energy data in TJ terms in the reported inventory, and for converting emission factors from kg emissions per tonne fuel, etc., to emissions per TJ.

The general method for calculating emissions from energy consumption is:

$$\circ \text{ Emissions}(E) = \text{Activity level}(A) \times \text{Emission Factor} (EF)$$

Emissions of pollutants from major manufacturing plants (point sources) are available from measurements or other plant-specific calculations. When such measured data are available it is possible to replace the estimated values by the measured ones:

$$\circ \text{ Emissions}(E) = [(A - A_{PS}) \times EF] + E_{PS}$$

Where  $A_{PS}$  and  $E_{PS}$  are the activity and the measured emissions at the point sources, respectively. Emissions from activity for which no point source estimate is available ( $A - A_{PS}$ ) are still estimated with the default emission factor. See section 1.4.2 for more information about the main emission model.

| Table 3.2 Average energy content (Net calorific value, NCV) and density of fuels*. |                    |                         |         |
|------------------------------------------------------------------------------------|--------------------|-------------------------|---------|
| Energy product                                                                     | Theoretical energy | Unit                    | Density |
| Coal                                                                               | 28.1               | GJ/tonne                | :       |
| Coke                                                                               | 28.5               | GJ/tonne                | :       |
| Petrol coke                                                                        | 35                 | GJ/tonne                | :       |
| Crude oil                                                                          | 42.3               | GJ/tonne                | 0.85    |
| Motor gasoline                                                                     | 43.9               | GJ/tonne                | 0.74    |
| Aviation gasoline                                                                  | 43.9               | GJ/tonne                | 0.74    |
| Kerosene (heating)                                                                 | 43.1               | GJ/tonne                | 0.81    |
| Jet kerosene                                                                       | 43.1               | GJ/tonne                | 0.81    |
| Auto diesel                                                                        | 43.1               | GJ/tonne                | 0.84    |
| Marine gas oil/diesel                                                              | 43.1               | GJ/tonne                | 0.84    |
| Light fuel oils                                                                    | 43.1               | GJ/tonne                | 0.84    |
| Heavy distillate                                                                   | 43.1               | GJ/tonne                | 0.88    |
| Heavy fuel oil                                                                     | 40.6               | GJ/tonne                | 0.98    |
| Bitumen                                                                            | 40.2               | GJ/tonne                | :       |
| Lubricants                                                                         | 40.2               | GJ/tonne                | :       |
| Natural gas (dry gas) (land)                                                       | 35.3               | GJ/1000 Sm <sup>3</sup> | 0.741   |
| Natural gas (rich gas) (offshore)                                                  | 40.3               | GJ/1000 Sm <sup>3</sup> | 0.851   |
| LPG                                                                                | 46.1               | GJ/tonne                | 0.53    |
| Refinery gas                                                                       | 48.6               | GJ/tonne                | :       |
| Blast furnace gas                                                                  | 6.1-10.0           | GJ/1000 Sm <sup>3</sup> | :       |
| Fuel gas <sup>3</sup>                                                              | 50                 | GJ/tonne                | :       |
| Landfill gas <sup>2,4</sup>                                                        | 50.4               | GJ/tonne                | :       |
| Biogas <sup>2,4</sup>                                                              | 50.4               | GJ/tonne                | :       |
| Fuel wood <sup>2</sup>                                                             | 16.8               | GJ/tonne                | 0.5     |
| Ethanol <sup>2</sup>                                                               | 26.8               | GJ/tonne                | 0.79    |
| Biodiesel <sup>2</sup>                                                             | 36.8               | GJ/tonne                | 0.88    |
| Wood waste <sup>2</sup>                                                            | 16.8               | GJ/tonne                | :       |
| Black liquor <sup>2</sup>                                                          | 7.2 - 9.2          | GJ/tonne                | :       |
| Wood pellets <sup>2</sup>                                                          | 17.3               | GJ/tonne                | :       |

Source: Statistics Norway/Norwegian Environment Agency

\*The theoretical energy content of a particular energy commodity may vary; Figures indicate mean values.

<sup>1</sup>kg/Sm<sup>3</sup>. Sm<sup>3</sup> = standard cubic meter (at 15 °C and 1 atmospheric pressure).

<sup>2</sup> Non-fossil emissions, not included in the inventory CO<sub>2</sub> totals

<sup>3</sup> In this inventory, fuel gas is a hydrogen-rich excess gas from petrochemical industry

<sup>4</sup> Landfill gas and other types of biogas are reported as methane content in the energy balance

For offshore activities and some major manufacturing plants (in particular refineries, gas terminals, cement industry, production of plastics, ammonia production, and methanol production), emissions of one or more compounds reported by the plants to the Norwegian Environment Agency are used, as described in equation 0 (see [Table 3.3](#)). In these cases, the energy consumption of the plants in question is subtracted from the total energy use before the general method is used to calculate the remaining emissions of the compound in question, to prevent double counting.

Emissions are reported to the Norwegian Environment Agency under several different reporting obligations. Most of the CO<sub>2</sub> emissions (except metal production, etc.) are reported as part of the Emissions Trading System (ETS).

In the general equation 0,  $E_{p5}$  represents the reported emission data, while  $A_{p5}$  represents the energy consumption at the plants. Note that for most plants, reported emissions are used only for some of the substances. For the remaining substances in the inventory, the general method with standard emission factors is used.

Reported figures are used for a relatively small number of plants, but as they contribute to a large share of the total energy use, a major part of the total emissions is based on such reported figures. [Table 3.3](#) gives an overview of the shares of estimated and reported emissions used in the inventory for the different sectors for the greenhouse gases CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in 2020.

In 2021, 92 per cent of the CO<sub>2</sub> emissions from Energy Industries were based on reported emissions and 21 per cent of the CO<sub>2</sub> emissions from Manufacturing Industries and Construction.



| Table 3.3 Share of total CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O emissions in the energy sector based on estimated and reported emission estimates for 2021. |                 |          |                 |          |                  |          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|----------|-----------------|----------|------------------|----------|
|                                                                                                                                                                             | CO <sub>2</sub> |          | CH <sub>4</sub> |          | N <sub>2</sub> O |          |
|                                                                                                                                                                             | Estimated       | Reported | Estimated       | Reported | Estimated        | Reported |
| <b>A. Fuel Combustion Activities (Sectoral Approach)</b>                                                                                                                    | 59%             | 41%      | 79%             | 21%      | 97%              | 3%       |
| <b>1. Energy Industries</b>                                                                                                                                                 | 8%              | 92%      | 18%             | 82%      | 80%              | 20%      |
| <b>a. Public Electricity and Heat Production</b>                                                                                                                            | 67%             | 33%      | 72%             | 28%      | 72%              | 298      |
| <b>b. Petroleum Refining</b>                                                                                                                                                | 0%              | 100%     | 80%             | 20%      | 100%             | 0%       |
| <b>c. Manufacture of Solid Fuels and Other Energy Industries</b>                                                                                                            | 0%              | 100%     | 0%              | 100%     | 100%             | 0%       |
| <b>2. Manufacturing Industries and Construction</b>                                                                                                                         | 79%             | 21%      | 100%            | 0%       | 97%              | 3%       |
| <b>a. Iron and Steel</b>                                                                                                                                                    | 14%             | 86%      | 100%            | 0%       | 100%             | 0%       |
| <b>b. Non-Ferrous Metals</b>                                                                                                                                                | 100%            | 0%       | 100%            | 0%       | 100%             | 0%       |
| <b>c. Chemicals</b>                                                                                                                                                         | 57%             | 43%      | 97%             | 3%       | 64%              | 36%      |
| <b>d. Pulp, Paper and Print</b>                                                                                                                                             | 100%            | 0%       | 100%            | 0%       | 100%             | 0%       |
| <b>e. Food Processing, Beverages and Tobacco</b>                                                                                                                            | 100%            | 0%       | 100%            | 0%       | 100%             | 0%       |
| <b>f. Non-metallic minerals</b>                                                                                                                                             | 28%             | 72%      | 100%            | 0%       | 100%             | 0%       |
| <b>g. Other (Oil drilling, construction, other manufacturing)</b>                                                                                                           | 100%            | 0%       | 100%            | 0%       | 100%             | 0%       |
| <b>3. Transport</b>                                                                                                                                                         | 100%            |          | 100%            |          | 100%             |          |
| <b>a. Civil Aviation</b>                                                                                                                                                    | 100%            |          | 100%            |          | 100%             |          |
| <b>b. Road Transportation</b>                                                                                                                                               | 100%            |          | 100%            |          | 100%             |          |
| <b>c. Railways</b>                                                                                                                                                          | 100%            |          | 100%            |          | 100%             |          |
| <b>d. Navigation</b>                                                                                                                                                        | 100%            |          | 100%            |          | 100%             |          |
| <b>e. Other Transportation (pipeline transport)</b>                                                                                                                         | (IE)            |          | (IE)            |          | (IE)             |          |
| <b>4. Other Sectors</b>                                                                                                                                                     | 100%            |          | 100%            |          | 100%             |          |
| <b>a. Commercial/Institutional</b>                                                                                                                                          | 100%            |          | 100%            |          | 100%             |          |
| <b>b. Residential</b>                                                                                                                                                       | 100%            |          | 100%            |          | 100%             |          |
| <b>c. Agriculture/Forestry/Fisheries</b>                                                                                                                                    | 100%            |          | 100%            |          | 100%             |          |
| <b>5. Other (Military)</b>                                                                                                                                                  | 100%            |          | 100%            |          | 100%             |          |

Source: Statistics Norway/Norwegian Environment Agency

Delimitation toward industrial processes etc.

The energy combustion sector borders to several other source categories. This section presents a more detailed description of the demarcation with other sectors used in the inventory, compared to section 3.1.

Energy consumption reported as activity data in the emission inventories is generally delimited in the same way as emissions. In cases where different substances are handled differently, the delimitation of energy consumption follows the delimitation of CO<sub>2</sub> emissions. Flaring is not reported as energy use under energy combustion (CRF 1A). Instead, flaring is reported under the following source categories:

- Flaring of oil and gas in refineries and in exploration/extraction is reported under fugitive emissions (CRF 1B).
- Flaring of oil and gas in manufacturing industries is reported under industrial processes (CRF 2), particularly under chemical industry (CRF 2B). (In the energy balance, flaring in manufacturing is reported as "losses".)
- Flaring of landfill gas is reported under waste incineration (CRF 5C).

Emissions from reducing agents are reported under industrial processes (CRF 2). This contrasts with the delimitation in the energy balance, where use as reducing agents is reported as energy consumption. In some special cases, CO<sub>2</sub> emissions from combustion are reported under other source categories, while emissions of other substances are reported in energy combustion (CRF 1A):

- CO-rich excess gas from metallurgical plants burnt on-site is reported under industrial processes (CRF 2C), according to IPCC guidelines (IPCC 2006). (Gas which is sold to other plants is reported under energy combustion (CRF 1A)).
- Coal used as fuel in some metallurgical plants which also use coal as a reducing agent is reported under industrial processes (CRF 2C).

CO<sub>2</sub> from combustion at petrochemical and ammonia plants is reported under industrial processes (CRF 2B). CO<sub>2</sub> from coke that is burnt off from catalytic crackers in refineries is reported under fugitive emissions (CRF 1B). This also applies to CO<sub>2</sub> from coke calcining kilns. In the energy balance, production, and energy consumption of non-commercial gases from coke burn-off in refineries, is recorded as "petroleum coke burn-off" and is included in "Other oil products. In these cases, energy consumption reported in the inventories follows the delimitation of the CO<sub>2</sub> emissions. This gives meaningful implied emission factors for CO<sub>2</sub>, while IEFs for other substances may be skewed.

At a small number of plants in the chemical industry, CO<sub>2</sub> emissions are reported in the ETS system from secondary fuels which are not included as energy use in the energy balance. The carbon in the fuels is likely reported as feedstock in the energy balance. Emissions from these plants are reported in their entirety as process emissions in 2B1 (ammonia) and 2B8 (petrochemical).

Emissions from paraffin wax are reported under Other Industrial processes (CRF 2G).

Combustion of solid waste and hazardous waste is reported under the energy section (district heating (CRF 1A1a) and in several manufacturing industries (CRF 1A2). No significant combustion of solid or hazardous waste occurs without energy recovery.

Combustion of landfill gas with energy recovery is reported under the energy section (mainly in Commercial/Institutional (CRF 1A4a)). Flaring is reported under waste incineration (CRF 5C), as mentioned above.

#### Emissions reported by plants: Energy data

Energy data for plants with reported emissions (APS in equation (3.2)) should be consistent both with the energy balance that is used for activity total A and with the reported emission data. Consistency with emission data means that the energy data should correspond to the same activity as the reported emissions.

Figures on plant energy used in the inventory are based on data reported from the plants to Statistics Norway. This ensures consistency with the energy balance.

In the emission trading system (ETS), emissions are, in most cases, reported together with data on the corresponding energy use. Usually, the energy data reported in the ETS are the same as those reported by the plants to Statistics Norway. However, for some plants, some of the energy data differ between reports to Statistics Norway and to the ETS. This leads to problems of consistency and deviations in implied emission factors. Statistics Norway will investigate large discrepancies between the energy reported under the ETS and the statistical surveys and make corrections where needed. However, the deviations are usually small, and generally, this should not be regarded as an important issue.

#### Emissions reported by plants: Allocation to combustion/processes

CH<sub>4</sub> emissions from an oil refinery are reported as a plant total, which includes both combustion and process emissions. These emissions must be allocated to the two emission categories. Emissions from combustion are calculated from energy use with

standard factors and the remaining part of reported emissions is reported in the inventory as process emissions.

#### Emissions reported by plants: Allocation to fuels

The following discussion is relevant for cases where emissions are reported with a fuel split. This applies to greenhouse gases reported to the UNFCCC, and to emission statistics in Statistics Norway's Statbank. In other reporting, emissions are aggregated over fuels.

For some plants and substances, emissions are reported by fuel, but in most cases reported combustion emissions are entered as a plant total. Emissions are then allocated to fuels based on standard EFs using equation (3.3):

$$E_{PS,f} = E_{PS} \times \frac{A_{PS,f} \times EF_f}{\sum_f A_{PS,f} \times EF_f}$$

where the subscript f denotes the fuel type.

This means that any deviations in data will be distributed across all fuels at the plant. Typical situations include:

- Plants with atypical fuels which differ from standard emission factors
- Plants with errors or other inconsistencies in energy data

In such cases, implied emission factors may deviate from the standard range also for other fuels than the one really affected.

Plants/substances which are entered by fuel currently include among others:

- CO<sub>2</sub> emissions from natural gas in almost all activities
- CO<sub>2</sub> emissions from cement production, 2008 and later
- CO<sub>2</sub> emissions from iron and steel production, 2008 and later
- CO<sub>2</sub> and several other substances from oil and gas production, offshore and onshore

Except for the cases listed above, fuel specific CO<sub>2</sub> emissions from the emission trading system reports (ETS) are not entered into the inventory, only the total plant emission is used.

#### **3.2.1.2 Activity data**

The energy balance defines the total energy consumption for which emissions are accounted. However, as explained above, a large part of the total emissions is based on reports from plants that use much energy, i.e., offshore activities and energy-intensive

industries on shore. Energy consumption from these plants is included in the energy balance. These consumptions are then subtracted from the energy balance before calculating the remaining emissions. Emissions are estimated using the standard method of multiplying energy use by emission factors described in equation (3.2).

The energy consumption data used in the emission calculations are, with few exceptions, taken from the annual energy balance compiled by Statistics Norway. The energy balance surveys the flow of the different energy carriers within Norwegian territory. These accounts include energy carriers used as raw materials and reducing agents, which are subtracted from the energy balance and are not included in the data used to estimate emissions from combustion. Figure 3-5 shows a flowchart of data and workflow in the energy balance system, with data input, production system and output. There is also an overview of agreements and data collection.

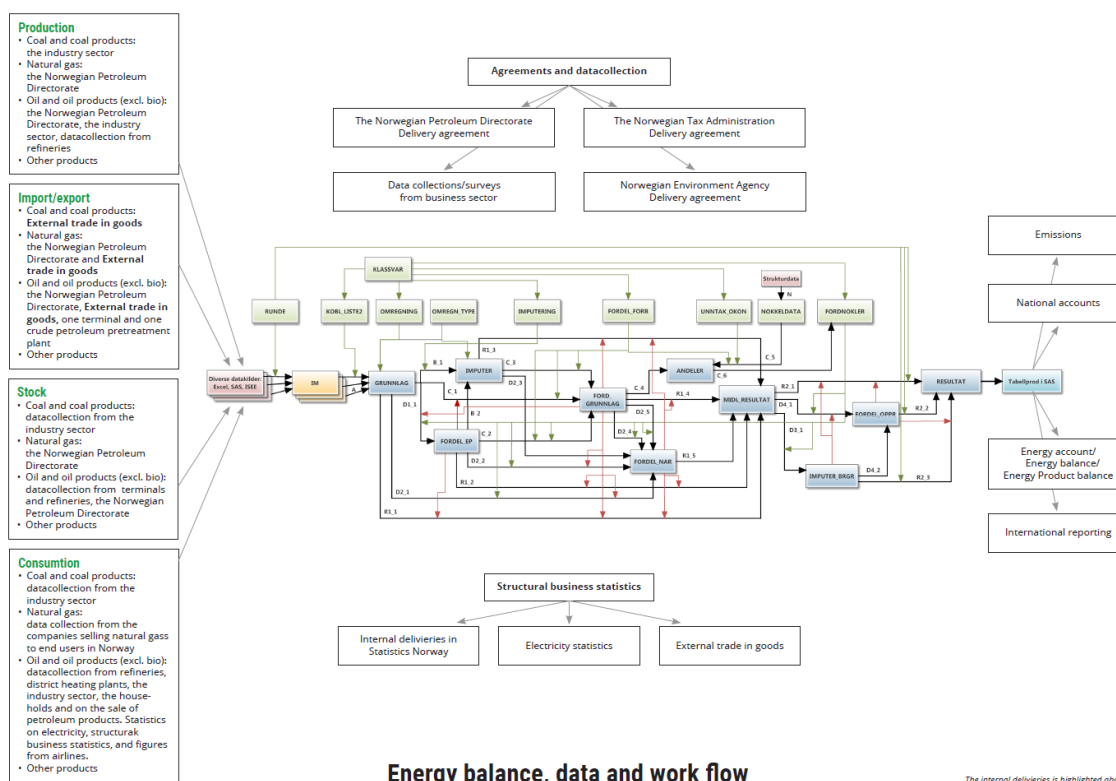


Figure 3-5: Data and workflow in the energy balance system

As some emissions vary with the combustion technology, a distribution between different sources is required. The total use of the different oil products is based on the Norwegian sales statistics for petroleum products. For other energy carriers, the total use of each energy carrier is determined by summing up reported/estimated consumption within the different sectors.

A short summary of the determination of amounts used by the main groups of energy carriers and of the distribution between emission sources is given below. The following paragraphs also explain the differences between energy accounts and the energy balance sheets, including the differences involved in Norway's submissions to international organizations. Energy balance sheets for all years in the reporting period are presented in Annex III of this report.

The independent collection of different energy carriers conducted by Statistics Norway, as described below, enables a thorough verification of the emission data reported by the entities to the Norwegian Environment Agency and Norwegian Petroleum Directorate that are included in the inventory.

#### Natural gas

Most of the combustion of natural gas is related to extraction of oil and gas on the Norwegian continental shelf. The amounts of gas combusted, distributed between gas turbines and flaring, are reported annually to Statistics Norway by the Norwegian Petroleum Directorate (NPD). These figures include natural gas combusted in gas turbines on the various oil and gas fields as well as on Norway's four gas terminals onshore. However, as explained above, emission figures of CO<sub>2</sub> from the largest gas consumers, e.g., offshore activities, gas terminals, and petrochemical industry, are figures reported by the plants. The data are considered to be of high quality, due to the Norwegian system of CO<sub>2</sub> taxation on fuel combustion.

The remaining combustion of natural gas is given by Statistics Norway's annual survey on energy use in manufacturing industries and by sales figures from distributors. Some manufacturing industries use natural gas in direct-fired furnaces; the rest is burnt in boilers and, in some cases, flared.

### Liquid fuels: LPG and secondary gases

Consumption of LPG in manufacturing industries is reported by the plants to Statistics Norway in the annual survey on energy use<sup>8</sup>. Figures on use of LPG in households and construction are based on sales figures, collected annually from the oil companies. Use in agriculture are prior to 2005 taken from agriculture statistics (Gundersen 2005). From 2005 and onwards, total consumption is given by the annual sales statistics for petroleum products and distributed to agriculture industry using the share of direct sales in 2009-2012. Until further work is done, the same distribution formula is applied to all these years.

Use of refinery gas is reported to Statistics Norway from the refineries. The distribution between direct-fired furnaces, flaring and boilers for the years prior to 2009, is based on information collected from the refineries in the early 1990's. From 2009, the energy consumption is reported according to the energy use at each plant. Emissions from combustion for energy purposes are reported under Petroleum refining (CRF 1A1b), emissions from flaring under fugitive emissions from Flaring (CRF 1B2c2) and emissions from cracker coke burn-off are reported under Refining/Storage (CRF 1B2a4).

Section 3.4 (CRF 1B2a4) describes the methodology for estimating emissions from crackers. The same distribution of emissions among different categories from combustion at the refineries is assumed for the whole time series. Comparisons made and previously reported to ERTs, shows consistency with what has been reported by the plants.

At some industrial plants, excess gas from chemical processes is burnt, partly in direct-fired furnaces and partly in boilers. These amounts of gases are reported to Statistics Norway. A petrochemical plant generates fuel gas derived from ethane and LPG. Most of the gas is burnt on-site, but some fuel gas is also sold to several other plants. All use of fuel gas is reported as energy consumption in the inventory. Almost all fuel gas is used at petrochemical and ammonia plants for which all emissions are reported as industrial processes in 2B1/2B8.

One of the petroleum refineries is also generating CO-rich gas as a by-product from coke burn-off in catalytic crackers. The gas is partly utilised as energy. In the energy balance, production and energy consumption of gases from coke burn-off in refineries, is recorded as "petroleum coke burn-off" and is included in "Other oil products.

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<sup>8</sup> <https://www.ssb.no/en/energi-og-industri/statistikker/indenergi>

### Liquid fuels: Oil products

The total use of the different oil products is based on Statistics Norway's annual sales statistics for petroleum products<sup>9</sup>. The statistics are based on annual reports from the oil companies and import data from the external trade statistics at Statistics Norway. This is also the data source for consumption in industries that do not collect their own data. For the time series from 1990 to 2009, monthly sales data are used in the energy balance. These data are also reported to Statistics Norway by the oil companies, but they do not contain as much information as the annual reports. In the monthly sales data, industrial distribution is specified by the oil companies but there is no information on individual buyers, such as organisation number, name, or address.

The annual sales data are considered reliable since all major oil companies selling oil products report to these statistics and have an interest in the quality of the data. The statistics are corrected for direct import by other importers or companies.

The use of sales statistics provides a total for the use of oil products. The use in the different sectors must sum up to this total. This is not the case for the other energy carriers. The method used for oil products defines use as identical to sales. Nevertheless, in practice, there will be annual changes in consumer stocks, which are not accounted for. In the statistics on sales of petroleum products there is a breakdown of sales by industry.

Direct sales to end users are linked to industries or households using the organisation number or other identifiers in the data from the oil companies, while sales to distributors of solid, liquid, and gaseous fuels remain attributed to the distributors. However, in energy balance all consumption must be broken down, also that which is sold via distributors. Thus, the breakdown by industry is therefore different in energy balance and in the statistics on sales of petroleum products. The method for this breakdown is described in Kittilsen et al. (2018).

Stationary combustion takes place in boilers and, in some manufacturing industries, in direct-fired furnaces. Small ovens can also be used, mainly in private households. From 1. January 2020 it is not allowed to use kerosene or heating oil for heating purposes in households, except for cottages which are not connected to the electricity grid.

Mobile combustion is distributed among different sources, described in more detail under the transport sector (sections 3.2.4 to 3.2.9).

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<sup>9</sup> <https://www.ssb.no/en/energi-og-industri/statistikker/petroleumsalg/aar>



In addition to oil products included in the sales statistics, figures on use of *waste oil* are given in Statistics Norway's industry statistics. Statistics Norway also collects additional information directly from a few companies using waste oil as fuel.

*Petrol coke* is not included in the sales statistics. Consumption data are collected as part of the coal and coke statistics, see below.

#### Coal, coke, and petroleum coke

Use of coal, coke and petrol coke in manufacturing industries is annually reported from the plants to Statistics Norway. The statistics cover all main consumers and are considered of high quality. More than 90 per cent of the coal and coke consumption in Norway is used as a reductant, so only a small part is used for combustion. Combustion of coal and cokes takes place partly in direct-fired furnaces, partly in boilers. The minor quantities burnt in small ovens in private households were estimated based on sales figures from coal/coke retailers until 2008. After 2008 this has not been recorded in the energy balance because of very small amounts. In addition, an insignificant figure of coal use in the agricultural sector has formerly been collected from the farmers. Since 2002, coal has not been used in Norwegian agriculture.

Several metallurgical plants generate blast furnace gas that is either burnt on-site or sold to adjacent plants. The gas is generated as a by-product from using coal or coke as a reductant in metal production. Some plants utilise the gas for energy purposes either directly on-site, or for electricity production or they sell it to other companies. Two ferroalloy plants sell parts of their blast furnace gas to other plants (an ammonia producer, a district heating plant, iron and steel producers and mineral industries), where it is used for energy purposes. Thus, these amounts are reported as energy consumption in the inventory.

#### Biofuels

Use of wood waste and black liquor in manufacturing industries is taken from Statistics Norway's annual survey on energy use in these sectors. For the years before 2005 and for 2012, the use of wood in households is based on the annual survey on consumer expenditure which gives the amount of wood burnt. The statistics cover purchase in physical units and estimates for self-harvest of wood. The survey figures refer to quantities acquired, which do not necessarily correspond to use. The survey gathers monthly data that cover the preceding twelve months; the figure used in the emission calculations (taken from the energy balance), is the average of the survey figures from the year in question

and the following year. For the period 2005-2011, the figures are based on responses to questions relating to wood-burning in Statistics Norway's Travel and Holiday Survey. The figures from the survey refer to quantities of wood used. The survey gathers quarterly data that cover the preceding twelve months. The figure used in the emission calculations is the average of 5 quarterly surveys. Since 2013 the figure used in the emission calculations is the average of 3 quarterly surveys. Figures on some minor use in agriculture and in construction have been derived from earlier surveys for these sectors. Combustion of wood product takes place in boilers and in small ovens in private households. Consumption figures for wood pellets and wood briquettes are estimated based on annual information from producers and distributors. Data on use of peat for energy purposes are not available, but according to the Energy Farm, the center for Bioenergy in Norway, such use is very limited (Hohle 2005).

The figures of biofuels (biodiesel and bioethanol) for road transportation are reported separately in the CRF tables. Figure 3-9 shows the consumption of biofuels in the transport sector. The amount of fuels sold is collected from the fuel marketing companies.

Sewage treatment plants and waste disposal sites utilizes biogas extracted at the plants, and reports quantities combusted (in turbines) and calculated CO<sub>2</sub> emissions. Other emissions are estimated by Statistics Norway, using the same emission factors as for combustion of natural gas in turbines.

### Waste

District heating plants and incineration plants annually report combusted amounts of waste (boilers) to Statistics Norway and the Norwegian Environment Agency. Amounts used in manufacturing industries are also reported to Statistics Norway.

According to the Norwegian Pollution Act, each incineration plant must report emission data for SO<sub>2</sub>, NO<sub>x</sub>, CO, NH<sub>3</sub>, particles, heavy metals and dioxins, and the amount of waste incinerated to the county governor. The county governor then reports this information to the Norwegian Environment Agency. If emissions are not reported, the general method used to estimate emissions from waste incineration is to multiply the amount of waste used by an appropriate emission factor. Normally a plant specific emission factor is built for the component in question. This factor is based on the ratio between previous emission figures and quantities of waste burnt. This factor is then multiplied with the amount of waste incinerated that specific year.

### Energy balance sheets vs energy accounts

There are two different ways of presenting energy balances: Energy balance sheets (EBS) and energy accounts. The energy figures used in the emission calculations are mainly based on the energy balance sheets. The energy balance sheets for the reporting period are presented in Annex III.

The energy accounts follow the energy consumption in Norwegian economic activity in the same way as the National accounts. All energy used by Norwegian enterprises and households is to be included. Energy used by Norwegian transport trades and tourists abroad is also included, while the energy used by foreign transport industries and tourists in Norway is excluded.

The energy balance sheet follows the flow of energy within Norway. This means that the figures only include energy sold in Norway, regardless of the users' nationality. This leads to different figures between the energy balance sheet and the energy account, especially for international shipping and aviation.

The energy balance sheet has a separate item for energy sources consumed for transportation purposes. The energy accounts place the consumption of all energy under the relevant consumer sector, regardless of whether the consumption refers to transportation, heating, or processing.

In response to previous review comments, the energy balance has been further disaggregated on energy products. The consumption of natural gas in the sector is divided among three flows in the energy balance:

- 8.3 – Thermal power plants: Auto producer generation (only segregated for 2007 onwards)
- 10 – Losses: Flaring
- 13 – Net consumption in manufacturing: Remaining natural gas.

Figures from the energy balance sheet are reported to international organizations such as the OECD and the UN. The energy balance sheet should therefore usually be comparable with international energy statistics.

Important differences between figures presented in the energy balance sheet (EBS) and figures used in the emission calculations (EC) are:

- Air transport: EC use only Norwegian domestic air traffic (excluding military), while EBS includes all fuel sold in Norway for air transport, including military and fuel used for international air transport
- Coal/coke used for non-energy purposes as a reductant: Non-energy consumption of coal/coke is specified in the EBS and included in “final consumption”, while coal/coke use as a reductant is included in final energy consumption together with coal/coke combustion. The EC include only energy used for combustion in the calculation of emissions from energy.

### 3.2.1.3 *Emission factors*

The standard emission factors used in the absence of more specific ones are addressed as general.

#### CO<sub>2</sub>

Emission factors for CO<sub>2</sub> are independent of technology and are based on the average carbon content of fuels used in Norway. The general emission factors for CO<sub>2</sub> used in the emission inventory are listed in [Table 3.4](#). For standard fuels such as refined petroleum products, these factors are used throughout the inventory. For other, more variable fuels, such as refinery gas and natural gas in the oil and gas industry, the table shows default factors that are used where more detailed data are unavailable. Thus, factors shown are not average factors across the inventory. Information on industry- and plant-specific factors are given in the category chapters.

As the primary energy data from the energy balance are provided in mass (or volume) terms, the factors per tonne or Sm<sup>3</sup> fuel are the ones that are actually used in the inventory.

| <b>Table 3.4 General emission factors for CO<sub>2</sub>.</b>            |                                        |                                     |
|--------------------------------------------------------------------------|----------------------------------------|-------------------------------------|
| <b>Energy product</b>                                                    | <b>Emission factors</b>                |                                     |
|                                                                          | <b>Tonne CO<sub>2</sub>/tonne fuel</b> | <b>Tonne CO<sub>2</sub>/TJ fuel</b> |
| <b>Coal</b>                                                              | 2.52                                   | 89.68                               |
| <b>Coke</b>                                                              | 3.19                                   | 111.93                              |
| <b>Petrol coke</b>                                                       | 3.59                                   | 102.57                              |
| <b>Crude oil</b>                                                         | 3.2                                    | 75.65                               |
| <b>Motor gasoline</b>                                                    | 3.13                                   | 71.3                                |
| <b>Aviation gasoline</b>                                                 | 3.13                                   | 71.3                                |
| <b>Kerosene (heating)</b>                                                | 3.15                                   | 73.09                               |
| <b>Jet kerosene</b>                                                      | 3.15                                   | 73.09                               |
| <b>Auto diesel</b>                                                       | 3.17                                   | 73.55                               |
| <b>Marine gas oil/diesel</b>                                             | 3.17                                   | 73.55                               |
| <b>Light fuel oils</b>                                                   | 3.17                                   | 73.55                               |
| <b>Heavy distillate</b>                                                  | 3.17                                   | 73.55                               |
| <b>Heavy fuel oil</b>                                                    | 3.2                                    | 78.82                               |
| <b>Natural gas (dry gas) (kg/Sm<sup>3</sup>) (land)</b>                  | 1.99                                   | 56.08                               |
| <b>Natural gas (rich gas) (kg/Sm<sup>3</sup>) (offshore)<sup>1</sup></b> | 2.34                                   | 58.09                               |
| <b>LPG</b>                                                               | 3                                      | 65.08                               |
| <b>Refinery gas</b>                                                      | 2.8                                    | 57.61                               |
| <b>Blast furnace gas</b>                                                 | 1.571                                  | 198                                 |
| <b>Fuel gas<sup>3</sup></b>                                              | 3.0                                    | 50                                  |
| <b>Landfill gas<sup>2,4</sup></b>                                        | 2.75                                   | 54.56                               |
| <b>Biogas<sup>2,4</sup></b>                                              | 2.75                                   | 54.56                               |
| <b>Fuel wood<sup>2</sup></b>                                             | 1.8                                    | 107.14                              |
| <b>Ethanol<sup>2</sup></b>                                               | 1.91                                   | 71.27                               |
| <b>Biodiesel<sup>2</sup></b>                                             | 2.85                                   | 77.45                               |
| <b>Wood waste<sup>2</sup></b>                                            | 1.8                                    | 100-110.77                          |
| <b>Black liquor<sup>2</sup></b>                                          | 1.8                                    | 195.65-250                          |
| <b>Charcoal</b>                                                          | 3.299                                  | 111.83                              |
| <b>Municipal waste</b>                                                   | 0.5498                                 | 47.81                               |
| <b>Special waste</b>                                                     | 3.2                                    | 78.82                               |

Source: Statistics Norway, Norwegian Petroleum Industry Association, SFT (1990), SFT (1996), Climate and Pollution Agency (2011b)

<sup>1</sup> The emission factor for natural gas used in the emission inventory varies as indicated in Table 3.30 and Table 3.6 .

<sup>2</sup> Non-fossil emissions, not included in the inventory CO<sub>2</sub> totals.

<sup>3</sup> In this inventory, fuel gas is a hydrogen-rich excess gas from petrochemical industry

<sup>4</sup> Landfill gas and other types of biogases are reported as methane content in the energy balance

<sup>5</sup> Emission factors per tonne blast furnace gas are not available. Emissions from off-site use of blast furnace gas are either measured or estimated from volume or energy use. Emissions from on-site use are covered in the IPPU section.

### CH<sub>4</sub> and N<sub>2</sub>O

For CH<sub>4</sub> and N<sub>2</sub>O, information on emission factors is generally very limited, because, unlike the CO<sub>2</sub> emission factors, they depend on the source of the emissions and the sector where the emissions take place. CH<sub>4</sub> and N<sub>2</sub>O emission factors for stationary combustion are default factors from IPCC (2006). Net calorific values from the energy balance have been used to combine the factors to primary energy data in physical units. Methane emission factor from fuel wood is taken from SINTEF (1995). Due to lack of data, some emission factors are used for sector/source combinations different from those they have been estimated for.

The general CH<sub>4</sub> and N<sub>2</sub>O emission factors used in the emission inventory for this source are listed in [Table 3.5](#) and [Table 3.7](#), respectively. [Table 3.6](#) and [Table 3.8](#) display the cases where emission factors other than the general ones have been used in the calculations.

| <b>Table 3.5 General emission factors for CH<sub>4</sub>, stationary combustion. Unit: kg CH<sub>4</sub> / TJ.</b> |                              |                     |                |                     |               |
|--------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------|----------------|---------------------|---------------|
| <b>Energy product</b>                                                                                              | <b>Direct-fired furnaces</b> | <b>Gas turbines</b> | <b>Boilers</b> | <b>Small stoves</b> | <b>Flares</b> |
| Coal                                                                                                               | 1                            |                     | 300            | 300                 |               |
| Coke                                                                                                               | 10                           |                     | 300            | 300                 |               |
| Petrol coke                                                                                                        | 3                            |                     | 10             |                     |               |
| Kerosene (heating)                                                                                                 |                              |                     | 10*            | 10                  |               |
| Marine gas oil/diesel                                                                                              | 10                           |                     | 10             |                     |               |
| Light fuel oils                                                                                                    |                              |                     | 10             | 10                  |               |
| Heavy distillate                                                                                                   | 10                           |                     | 10             | 10                  |               |
| Heavy fuel oil                                                                                                     | 10*                          |                     | 10*            |                     |               |
| Natural gas (dry gas) (land)                                                                                       | 5                            | 25.63               | 5              |                     | 6.76          |
| Natural gas (rich gas) (offshore)                                                                                  | 4.4*                         | 22.58               | 4*             |                     | 5.96          |
| LPG                                                                                                                |                              |                     | 5              | 5                   |               |
| Refinery gas                                                                                                       | 1                            |                     | 1              |                     | 5.76          |
| Blast furnace gas                                                                                                  | 0.67                         |                     | 0.67*          |                     |               |
| Fuel gas                                                                                                           | 1                            |                     | 1              |                     | 1.08          |
| Landfill gas                                                                                                       | 5                            |                     | 5              |                     | 7.34          |
| Fuel wood                                                                                                          |                              |                     |                | 228-959*            |               |
| Wood pellets                                                                                                       |                              |                     | 11             | 300                 |               |
| Wood briquettes                                                                                                    |                              |                     | 11*            |                     |               |
| Wood waste                                                                                                         |                              |                     | 11*            |                     |               |
| Black liquor                                                                                                       |                              |                     | 3              |                     |               |
| Charcoal                                                                                                           | 200                          |                     |                | 203                 |               |
| Municipal waste                                                                                                    |                              |                     | 30             |                     |               |
| Special waste                                                                                                      | 30                           |                     | 30             |                     |               |

Source: IPCC (2006), SFT (1996), SINTEF (1995) and OLF (1994)

\*Numbers have exceptions for some sectors, see Table 3.31

| <b>Table 3.6 Exceptions from the general factors for CH<sub>4</sub>, stationary combustion. Unit: kg CH<sub>4</sub>/TJ.</b> |                                                                     |                                |                                              |
|-----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|--------------------------------|----------------------------------------------|
| <b>Emission factor</b>                                                                                                      | <b>Fuel</b>                                                         | <b>Source</b>                  | <b>Sectors</b>                               |
| <b>3</b>                                                                                                                    | Kerosene (heating), marine diesel; light fuel oil, heavy distillate | Direct fired furnaces          | Energy industry and manufacturing of product |
| <b>3</b>                                                                                                                    | Heavy fuel oil                                                      | Direct fired furnaces, boilers | Energy industry and manufacturing of product |
| <b>1</b>                                                                                                                    | LPG                                                                 | Boilers                        | Energy industry and manufacturing of product |
| <b>1.14</b>                                                                                                                 | Natural gas                                                         | Direct fired furnaces, boilers | Extraction of oil and gas                    |
| <b>1</b>                                                                                                                    | Natural gas                                                         | Direct fired furnaces, boilers | Energy industry and manufacturing of product |
| <b>0</b>                                                                                                                    | Blast furnace gas                                                   | Boilers                        | Refinery                                     |
| <b>1</b>                                                                                                                    | Landfill gas, Biogas                                                | Gas turbines, boilers          | Energy industry and manufacturing of product |
| <b>30</b>                                                                                                                   | Wood waste                                                          | Boilers                        | Energy industry and manufacturing of product |
| <b>300</b>                                                                                                                  | Wood briquettes                                                     | Boilers                        | Private households                           |
| <b>959</b>                                                                                                                  | Wood                                                                | Stoves (Pre-1998 technology)   | Private households                           |
| <b>228</b>                                                                                                                  | Wood                                                                | Stoves (Post-1998 technology)  | Private households                           |
| <b>315</b>                                                                                                                  | Wood                                                                | Open fireplaces                | Private households                           |

Source: IPCC (2006), SFT (1996), SINTEF (1995), OLF (1994) and Morten Seljeskog et al. (2017). The emission factor for newer stoves in residential wood burning is used increasingly as time goes on due to older stoves being phased out in Norwegian households.



| <b>Table 3.7 General emission factors for N<sub>2</sub>O, stationary combustion. Unit: kg N<sub>2</sub>O/TJ.</b> |                              |                     |                |                     |               |
|------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------|----------------|---------------------|---------------|
| <b>Energy product</b>                                                                                            | <b>Direct-fired furnaces</b> | <b>Gas turbines</b> | <b>Boilers</b> | <b>Small stoves</b> | <b>Flares</b> |
| Coal                                                                                                             | 1.50                         |                     | 1.50           | 1.50                |               |
| Coke                                                                                                             | 1.50                         |                     | 1.50           | 1.50                |               |
| Petrol coke                                                                                                      | 0.60                         |                     | 0.60           |                     |               |
| Kerosene (heating)                                                                                               |                              |                     | 0.60           | 0.60                |               |
| Marine gas oil/diesel                                                                                            | 0.60                         | 0.60                | 0.60           |                     |               |
| Light fuel oils                                                                                                  |                              |                     | 0.60           | 0.60                |               |
| Heavy distillate                                                                                                 | 0.60                         |                     | 0.60           | 0.60                |               |
| Heavy fuel oil                                                                                                   | 0.60                         |                     | 0.60           |                     |               |
| Natural gas (dry gas) (land)                                                                                     | 0.10*                        | 0.10*               | 0.10*          |                     | 0.56          |
| Natural gas (rich gas) (offshore)                                                                                | 0.09*                        | 0.09*               | 0.09*          |                     | 0.50          |
| LPG                                                                                                              |                              |                     | 0.10           | 0.10                |               |
| Refinery gas                                                                                                     | 0.10                         |                     | 0.10           |                     | 0.49          |
| Blast furnace gas                                                                                                | 0.07                         |                     | 0.07           |                     |               |
| Fuel gas                                                                                                         | 0.10                         |                     | 0.10           |                     | 0.48          |
| Landfill gas                                                                                                     | 0.10                         | 0.10                | 0.10           |                     | 0.03          |
| Fuel wood                                                                                                        |                              |                     |                | 4                   |               |
| Wood pellets                                                                                                     |                              |                     | 4              | 4                   |               |
| Wood briquettes                                                                                                  |                              |                     | 4              |                     |               |
| Wood waste                                                                                                       |                              |                     | 4              |                     |               |
| Black liquor                                                                                                     |                              |                     | 2              |                     |               |
| Charcoal                                                                                                         | 4                            |                     |                | 1                   |               |
| Municipal waste                                                                                                  |                              |                     | 4              |                     |               |
| Special waste                                                                                                    | 4                            |                     | 4              |                     |               |

Source: IPCC (2006), SFT (1996), SINTEF (1995) and OLF (1994)

\*Numbers have exceptions for some sectors, see Table 3.8

| <b>Table 3.8 Exceptions from the general factors for N<sub>2</sub>O, stationary combustion. Unit: kg N<sub>2</sub>O/TJ.</b> |             |                                              |                           |
|-----------------------------------------------------------------------------------------------------------------------------|-------------|----------------------------------------------|---------------------------|
| <b>Emission factor</b>                                                                                                      | <b>Fuel</b> | <b>Source</b>                                | <b>Sectors</b>            |
| <b>0.11</b>                                                                                                                 | Natural gas | Direct-fired furnaces, gas turbines, boilers | Extraction of oil and gas |

Source: Statistics Norway

### 3.2.1.4 Uncertainties and time-series consistency

Uncertainty estimates for greenhouse gases are presented and discussed in Annex II, as well as under the individual underlying source categories described in the following.

In general, the total energy use is less uncertain than the energy use in each sector. For some sectors, (e.g., the energy and manufacturing industries) the energy use is well known. However, in the case of households and service sectors energy use is more uncertain. The energy use in the most uncertain sectors has been adjusted in the official energy statistics, so that the sum of the energy use in all sectors equals the total sales.

The current method is based on uncertainty estimates for the individual source categories. The main categories are:

- Use of oil products: Total amounts are given by the petroleum sales statistics. The uncertainty for total sales is considered to be low due to reliable and complete sales statistics, CO<sub>2</sub>-tax and other taxes. The project undertaken for the RA/SA also underlines that this statistic is reliable. However, the allocation of the total consumption to individual sources is more uncertain.
- Reported emissions from other fuels, primarily natural gas: Uncertainty data for emissions and energy use are provided in ETS reports. A comparison undertaken as part of the RA/SA project shows that there is good correspondence between the energy consumption by plants covered by the EU ETS and the voluntary agreement and Statistics Norway's own statistics. This also indicates that the energy use in manufacturing industry in the inventory is reliable.

The analyses have not uncovered any major completeness problems in the consumption data. Thus, we have chosen to use the within-source uncertainties in the uncertainty analysis, and to discuss the RA/SA problems in a separate section.

Time series consistency is obtained by the continuous effort to recalculate the entire time series whenever a new source is included in the inventory or new information, or methodologies are obtained. However, data availability both for activity data and reported emissions have generally improved over time and new data are included in the emission estimates when deemed of better quality. This causes a degree of time series inconsistency, but the entire time series is considered when new data are included, and efforts made to take the new information into account for all years.

When it comes to activity data, the statistics that form the basis for the energy consumption are not always complete from 1990 onwards. For instance, the waste statistics that form the basis for the waste incineration started in 1995. For the years prior to this, activity data have been backwards extrapolated to ensure consistency in emission estimates.

Emissions reported from the plants are in most cases of good quality, but it may be unfeasible to obtain the estimates for the entire time series. In cases where the reported emissions are deemed to add to accuracy or level of detail in the emission inventory, and the reported figures are unavailable for parts of the time series, reported figures are used although this introduces a certain level of inconsistency. However, emissions for the rest of the time series are calculated based on fuel consumption and standard emission factors, and checks have been made to ensure that the two methodologies give comparable emission estimates. Times series consistency is thus considered to be met.

### **3.2.1.5 Category-specific QA/QC and verification**

Emission sources in the energy sector are subjected to the QA/QC procedures described in Section 1.2.3 and in Annex VII QA/QC of point sources. Several documentation reports have been published describing the methodologies used for road traffic (Holmengen & Fedoryshyn 2015) and navigation (Flugsrud et al. 2010; Tornsjø 2001). The methodology for aviation is described in an internal document from Statistics Norway (Skullerud 2014).

The energy statistics that form the basis for the energy balance and energy accounts are subject to individual QA/QC procedures which are not directly linked to the emission inventory system. For the survey on energy use in manufacturing industries, data are edited in a top-down manner, where large units are edited first. The responses from the plants are subject to a set of automated controls that flag outliers and other possible errors (Statistics Norway 2012). The statistics on sales of petroleum products are checked by comparing total sales for each company with additional information from the company. In addition, the companies check that the complete statistics correspond with their own figures. The companies receive tables containing their sales figures, total sales and market shares (Statistics Norway Annually-a).

Plant specific emission data included in the greenhouse gas inventory are as explained above based on three different reports. Firstly, the annual report that each plant with a permit from the Norwegian Environment Agency has a legal obligation to submit. This report covers all activity at the plant. Emissions data from the largest plants are included in the national greenhouse gas inventory. Secondly, from 2005, we have also received an annual report from entities included in the ETS. In connection with establishing the ETS the plants estimates were quality checked for the time series and specific emphasis on the years 1998-2001. During this process a consistent time series were established for the period from 1990. Thirdly, the Norwegian Environment Agency also receives emission data through a voluntary agreement first established in 1997 between the authority and the

industry. From 2005, the agreement covers sectors that are not yet included in the ETS. Data received by the Norwegian Environment Agency through the different reporting channels described above are controlled thoroughly by the Norwegian Environment Agency and Statistics Norway. Especially the emission data plants included in the ETS and in the voluntary agreement are verified extensively. See Annex VII QAQC of point sources.

### **3.2.1.6 Category-specific recalculations**

Most of the recalculations have been performed for the last inventory year (2020), because some of the energy figures used in the previous inventory were preliminary. There will always be some changes in the energy figures. For petroleum products, corrections in one sector will lead to adjustments in other sectors, as total use of oil products must sum up to national sales. Now the final figures for energy use are available and are used in the emission calculations.

See Chapter 10 Recalculations for more details.

### **3.2.1.7 Category-specific planned improvements**

The Norwegian Emission Inventory was subjected to an in-country review in 2018. The team of experts expressed special concerns about the size of the differences in energy use and emissions as estimated by the reference and the sectoral approach. These concerns were addressed in a Saturday Paper. Annex XI and XII provide information on how Norway has responded to solve the issues raised in the Saturday Paper.

## **3.2.2 Energy industries, 1A1 (Key category for CO<sub>2</sub> and CH<sub>4</sub>)**

### **3.2.2.1 Description**

Energy industries include emissions from electricity and heat generation and distribution, extraction and production of oil and natural gas, coal production, gas terminals and oil refineries. Norway produces electricity mainly from hydropower and therefore, emissions from electricity production are small compared to most other countries. Due to the large production of oil and gas, emissions from combustion in energy production are nevertheless high.

It is important to specify that only emissions from energy combustion for energy purposes are included in section 3.2 Energy Combustion and therefore in the source category Energy industries (CRF 1A1). Emissions from combustion not for energy purposes, e.g., flaring, are included in section 3.3, 3.4 and 7.5.

Emissions from drilling at moveable offshore installations are included in section 3.2. Emissions from these installations, while not in operation (during transport, etc.), are included with 1A3d Navigation.

In 2021, GHG emissions from the energy industries accounted for 39 per cent of the energy sector's total emissions and 27 per cent of the total emissions in Norway. Emissions increased by 84 per cent during the period 1990-2021, primarily due to the increased activity in the oil and gas extraction sector. In 2009, however, the increase was due to approximately one million tonne higher CO<sub>2</sub> emissions from the start-up of a gas fired electricity power plant, while the rather important reduction between 2011 and 2012 is the result of decreased emissions from the same sector.

According to the approach 2 key category analysis for 1990 and 2021, this sector is, in conjunction with stationary combustion in sectors 1A2 and 1A4, a key category with respect to:

- Emissions of CO<sub>2</sub> from the combustion of liquid fuels, gaseous fuels, and other fuels in level in 1990 and 2021, and in trend
- Emissions of CO<sub>2</sub> from the combustion of solid fuels in level in 1990 and 2021
- Emissions of CH<sub>4</sub> from the combustion of biomass and gaseous fuels in level in 1990 and 2021 and in trend

### **3.2.2.2 Methodological issues**

A description of the general method used for estimating emissions from fuel combustion is given in section 3.2.1.1. However, most of the reported emissions in this source category are from the annual report from the entities to the Norwegian Environment Agency and the Norwegian Petroleum Directorate. The guidelines for estimating and reporting emissions are lengthy and in Norwegian, so instead of attaching these to the NIR, URLs are provided in section 3.2.1.1 and in Annex VII.

In the case of waste incineration, further specifications on the methodology are given below.

#### Oil refineries

The emissions from oil refineries are based on annual report from each refinery to the Norwegian Environment Agency. The data are taken from the mandatory reporting obligation that is a part of the plants permits given by the authorities up until 2004, however and from 2005 and onwards, emission data are taken from the emission trading

system. The distribution of emissions between flaring and energy utilisation of refinery gas in the whole period from 1990 is based on plant and year specific figures. Emissions from energy utilization are reported in petroleum refining (CRF 1A1b) and from flaring in fugitive emissions from flaring (CRF 1B2c).

One of the refineries has a catalytic cracker. Emissions from coke burn off on the catalyst at the cracker are, since they are not for energy purposes, reported in Fugitive Emissions from Oil (CRF 1B2a).

#### Waste incineration – N<sub>2</sub>O

Emissions of N<sub>2</sub>O are derived from the emissions of NO<sub>x</sub>, which are reported from each plant to the Norwegian Environment Agency. More specifically, an estimated amount of 2.5% of this NO<sub>x</sub> is subtracted and reported to UNFCCC as N<sub>2</sub>O (SFT 1996). Accordingly, the net NO<sub>x</sub> emissions constitute 97.5% of the emissions reported by the plants. For some years, emissions of NO<sub>x</sub> have not been reported for a number of plants. In these cases, specific emission factors for the plants have been made, based upon earlier emissions and amounts of waste incinerated. These new factors have been used to estimate the missing figures.

#### **3.2.2.3 Activity data**

##### Electricity and heat generation and distribution

The energy producers annually report their use of different energy carriers to Statistics Norway. There is only some minor use of oil products at plants producing electricity from hydropower. Combustion of coal at Norway's only dual-purpose power plant at Svalbard/Spitsbergen is of a somewhat larger size. The amount of waste combusted at district heating plants is reported annually both to Statistics Norway and the Norwegian Environment Agency, see [Table 3.9](#). Data are considered to be of high quality.

| <b>Table 3.9 Amount of waste combusted at waste incineration plants. 1990-2021. Unit: 1000 tonnes.</b> |      |      |      |      |      |      |      |      |      |      |      |      |
|--------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|                                                                                                        | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| <b>Amount of waste incinerated</b>                                                                     | 225  | 367  | 524  | 626  | 1044 | 1618 | 1562 | 1645 | 1677 | 1608 | 1643 | 1560 |

Source: Statistics Norway and Norwegian Environment Agency

##### Oil refineries

The oil refineries annually report their use of different energy carriers to Statistics Norway. Refinery gas is the most important, but there is also some use of LPG and oil products. Emissions included in inventory for this category are from the refineries annual report to

the Norwegian Environment Agency. Emissions from the catalytic cracker at one refinery are reported in Refining/Storage (CRF 1B2a4).

#### Coal production

Norway's coal production takes place on Svalbard. The only coal producing company reports its coal consumption and some minor use of oil products annually. In addition to emissions related to Norway's own coal production, emissions from Russian activities are also included in the Norwegian emission inventory. As Russian activity data are scarce, emissions from an estimated quantity of coal combusted in Russian power plants are calculated. Since 1999, there has been only one such plant; in earlier years there were two.

#### Extraction of oil and natural gas

Production of oil and natural gas is the dominating sector for emissions from combustion in the energy industries in Norway. The Norwegian Petroleum Directorate reports annually the amounts of gas combusted in turbines and diesel burnt in turbines and direct-fired furnaces on the oil and gas fields. The data are considered of high quality due to the CO<sub>2</sub> tax on fuel combustion. The activity data are used for 1990-2002. From 2003 onwards, reported emission figures from the field operators are reported into the Footprint reporting tool.

The guidelines for estimating and reporting emissions are lengthy and in Norwegian, so instead of attaching these to the NIR URLs are provided in references. Annex VII describes QA/QC performed for plant specific emission data use in the inventory.

The reporting into Footprint (for offshore activities) is described in guidance documents (Miljødirektoratet 2021; Norwegian Oil and Gas 2021a).

Combusted amounts are generally reported in volume or mass terms, with little or incomplete information on energy content. Conversion of reported data to energy terms is discussed below in the section on emission factors.

#### Gas terminals

Norway has four gas terminals, where natural gas from the Norwegian continental shelf is landed, treated, and distributed. The first started up in 1985, one in 1996 and two in 2007.

Annual figures on natural gas combusted in turbines and flared are reported to the Norwegian Environment Agency and the Norwegian Petroleum Directorate. Emissions

included in inventory for this category are from the gas terminals' annual reports to the Norwegian Environment Agency.

In addition, emissions from two LNG plants and an oil terminal are reported in the extraction category, with data sources as for the gas terminals.

Some of the terminals use electricity from the grid as their main energy source, while others use gas derived from the natural gas feed.

#### **3.2.2.4 Emission factors**

The emission factors used for energy industries are presented in section 3.2.1.3. For some industries and components, more information about the derivation of the emission factors is given below.

##### Liquid fuels in electricity generation

The CO<sub>2</sub> implied emission factor for use of liquid fuels in electricity generation varies significantly over the period, from a regular factor around 73-74 t/TJ down to around 50 t/TJ. The IEF drops from 2010 onwards.

The drop in IEF is due to the use of refinery gas at a heat and power plant adjacent to a refinery. The NCV for refinery gas is about 11% higher than that for other liquid fuels (Table 3.2), and the emission factor is 20% lower. This change in energy mix explains the reduction in the IEF for liquid fuels used in this source category from 2009 to 2011.

Emissions from consumption of refinery gas included in the inventory are taken from the ETS reports and adjusted for the backflow of fuel gas to refinery. The removed amount of CO<sub>2</sub> is included in Petroleum refining (CRF 1A1b). The adjustment for backflow is because the amount and composition of the gas are measured before a separation facility that removes excess hydrogen together with some hydrocarbons.

##### Gas in electricity generation

The CO<sub>2</sub> implied emission factor for use of natural gas in electricity generation varies significantly over the period, from 55.1 t/TJ to over 58.7 t/TJ.

The variation is primarily a result of the economics of gas power production. Thus, the relative contributions of plants with different plant-specific factors (as based on reports to the Emissions Trading System) also vary significantly. This accounts for the changes in the time series.



### Coal in electricity and heat production

The CO<sub>2</sub> factor for solid fuels in electricity generation is low, at 89.7 t/TJ. The emissions in this category is from use of coal at Svalbard. The coal mined at Svalbard has a low carbon emission factor.

The CO<sub>2</sub> factor for solid fuels in heat generation is high and variable, ranging from 164 to 202 t/TJ. The emissions in this category are from blast furnace gas which is sold from a ferroalloy plant to heat distributors. The emissions are based on reports from the plants, from 2008 onwards as part of the Emissions Trading System.

### Waste incineration

The emission factors for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O from combustion of waste (fossil part only) are displayed in [Table 3.4](#), [Table 3.5](#) and [Table 3.7](#), respectively. Emission factors for CH<sub>4</sub> have been calculated by SFT (1996).

The CO<sub>2</sub> emission factor for the fossil part of waste combusted in waste incineration plants in Norway was revised in 2014 (Fedoryshyn 2015). The new factor is based on the assumption that 2.708 tonnes CO<sub>2</sub> per tonne plastic are combusted (based upon the same composition of polymers combusted as in Danish calculations (Nielsen et al. 2010) and that 20% of the combusted waste was fossil in 2009 (Norwegian Climate and Pollution Agency 2011). The new factor is a time series that is based on the mean annual change in the fossil share of combusted waste. This change is calculated using the data from Waste accounts Statistics (Statistics Norway Annually-c) in the period of 1995-2011. For years when data from Waste accounts are not available, the CO<sub>2</sub> emission factor is held constant: in 1994 and before, the 1995 factor is used, while 2011 factor is used in the years after 2011. The energy content of waste used in the new calculation is 11.5 GJ per tonne waste and is based on a report from Avfall Norge (Marthinsen et al. 2010).

### Oil refineries

The CO<sub>2</sub> emission factor for combustion of refinery gas is based on daily or weekly plant-specific measurements. The refinery gas consists of hydrogen and various hydrocarbons. The composition is variable, leading to changing emissions factors measured as tonne CO<sub>2</sub>/tonne fuel or tonne CO<sub>2</sub>/TJ. High hydrogen content leads to low emission factors as measured in tonne CO<sub>2</sub>/TJ. As an example, a gas with 40% hydrogen and 60% hydrocarbons with an average carbon number of 2 gives an emission factor of 50 tonne CO<sub>2</sub>/TJ. In the Norwegian inventory, the emission factor varies in the range 45-60 tonne CO<sub>2</sub>/TJ.

## Extraction of oil and natural gas

### *Offshore operations*

For all years up to 2002, emissions of CO<sub>2</sub> from gas combustion offshore are calculated by Statistics Norway based on activity data reported by the oil companies to the Norwegian Petroleum Directorate and the Norwegian Environment Agency and the emission factors shown in [Table 3.5](#). For the years 2003 and onwards, the data used in the inventory are emissions reported directly by the field operators. The operators are obliged to report these and other emissions annually to the Norwegian Petroleum Directorate and the Norwegian Environment Agency.

The CO<sub>2</sub> emission factor used for all years leading up to 1998 and for all fields except one is one average (standard) factor based upon a survey carried out in the early 1990s (OLF 1993). From 1999 and onwards, the employed emission factors reflect increasingly field specific conditions, as individual emission factors have been reported directly from fields. The measurement frequency varies among the installations. An increasing number uses continuous gas chromatography analysis. [Table 3.10](#) displays the time series of such emission factors, expressed as averages, and based on data reported in Footprint. Footprint is the reporting system in which field operators report emissions data.

Since 2008, offshore gas combustion has been included in the European emission trading system (ETS).

The carbon content of gas burnt varies considerably between the various oil and gas fields. These changes are reflected in the reported emissions. Up to the early 1990s, most of the gas was used in the Ekofisk area, which has a below average carbon content. From around 2000, fields with higher carbon content came into production. Since the last few years, there has been a shift towards fields with somewhat lower carbon content, again.

Activity data are reported in volume or mass terms, as noted in the AD section above. The preparation of the CO<sub>2</sub> inventory for the CRF reporting is done totally without referring to the energy content. Conversion to energy terms is not standardised throughout the energy and emissions statistical systems, and this makes it difficult to present consistent data in energy terms.

Emission factors for the offshore part of the extraction industry are shown in [Table 3.10](#). The table shows factors both in kg CO<sub>2</sub>/Sm<sup>3</sup> and kg CO<sub>2</sub>/GJ. The factors  $f_{CO_2_{vol}}$  in kg CO<sub>2</sub>/Sm<sup>3</sup> are annual averages from total emission and consumption data as reported in

Footprint. The factors  $f\text{CO}_{2,E}$  in kg CO<sub>2</sub>/GJ are back-calculated from the  $f\text{CO}_{2,V}$  values using a formula from the reporting guidance document Norwegian Oil and Gas (2021b):

$$f\text{CO}_{2,\text{vol}} = 0.0724 \cdot \text{NCV}_{\text{vol}} + 0.5771$$

where  $f\text{CO}_{2,\text{vol}}$  is given in kg CO<sub>2</sub>/Sm<sup>3</sup> and  $\text{NCV}_{\text{vol}}$  in MJ/Sm<sup>3</sup>.

The formula is originally meant to estimate CO<sub>2</sub> emissions when only NCV values is known. Here, the expression is used in reverse to convert the emission factors to MJ terms. Using the fact that  $f\text{CO}_{2,E} = f\text{CO}_{2,\text{vol}} / \text{NCV}_{\text{vol}}$  and inserting the expression above, solved for  $\text{NCV}_{\text{vol}}$ , one gets

$$f\text{CO}_{2,E} = 0.0724 / (1 + 0.5771 / f\text{CO}_{2,\text{vol}})$$

This formula is used to obtain the data for kg CO<sub>2</sub>/GJ in the table.

**Table 3.10 Average emission factors of CO<sub>2</sub> from the combustion of natural gas in turbines at offshore gas and oil fields. 1990-2021.**

|                                     | 1990  | 1995 | 2000  | 2005  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  | 2021 |
|-------------------------------------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| kg CO <sub>2</sub> /Sm <sup>3</sup> | 2.40  | 2.38 | 2.56  | 2.43  | 2.36  | 2.37  | 2.36  | 2.36  | 2.35  | 2.38  | 2.37  | 2.34  | 2.33  | 2.30  | 2.30  | 2.32 |
| kg CO <sub>2</sub> /GJ              | 60.82 | 59.1 | 61.71 | 60.45 | 56.52 | 56.81 | 57.06 | 55.42 | 56.75 | 58.43 | 57.91 | 57.46 | 60.09 | 58.93 | 59.09 | 59.1 |

Source: Statistics Norway, Norwegian Environment Agency and Norwegian Petroleum Directorate, Footprint reporting system

### Gas terminals

There are four gas terminals in Norway. The CO<sub>2</sub> emission factors for combustion of natural gas on the terminals are based on continuous or daily plant-specific measurements.

Since 2005, the terminals have been included in the emission trading system (ETS). The average CO<sub>2</sub> emission factors for fuel gas varies between terminals.

At the two terminals that account for most of the CO<sub>2</sub> emissions, some CO<sub>2</sub> derived from the natural gas feed is entered into the fuel gas. This leads to low CO<sub>2</sub> emissions per tonne gas and high emissions per MJ. In [Table 3.11](#), emission factors in t CO<sub>2</sub>/t fuel gas are given for these two terminals for some years for which data were readily available. Information on energy content and gas volume was not available.

**Table 3.11 Average emission factors of CO<sub>2</sub> from two major natural gas terminals. 2008-2021. t CO<sub>2</sub>/t fuel gas.**

|           | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Kårstø    | 2,37 | 2,33 | 2,27 | 2,22 | 2,21 | 2,26 | 2,18 | 2,20 | 2,24 | 2,23 | 2,25 | 2,28 | 2,36 | 2,55 |
| Hammefest |      |      |      |      |      | 2,49 | 2,46 | 2,46 | 2,45 | 2,45 | 2,45 | 2,45 | 2,47 | 2,67 |

Source: Norwegian Environment Agency

### 3.2.2.5 Uncertainties and time series consistency

The uncertainty analysis performed for the energy industries (Annex II) has shown that the uncertainty in the activity data is  $\pm 3\%$  of the mean for oil,  $\pm 4\%$  for gas and  $\pm 5\%$  of the mean for coal/coke and waste.

In the case of the emission factors for CO<sub>2</sub>, the uncertainty is  $\pm 3\%$  of the mean for oil,  $\pm 3.5\%$  for gas,  $\pm 7\%$  for coal/coke and gas and  $\pm 30\%$  of the mean for waste.

Emission factors for CH<sub>4</sub> and N<sub>2</sub>O are very uncertain. Distributions are strongly skewed with uncertainties which lie below and above the mean by a factor of 2 and 3, respectively.

The EU ETS emission estimates are available for all years since 2005. The information included in the ETS cannot reasonably be obtained for the time series 1990-2004. Thus, the use of this relatively new data source introduces a degree of inconsistency in the time-series. However, the energy consumption reported under the ETS system is consistent with the energy consumption reported to Statistics Norway for individual plants. In addition, the CO<sub>2</sub> emission estimates are consistent with the emissions reported into Footprint for offshore activities and into Altinn for land-based industries. These are the data sources used for emissions, for the years prior to the introduction of the EU ETS scheme. It has thus been assumed that time-series consistency is not significantly affected, and that the emission trend is reliable.

### 3.2.2.6 Category-specific QA/QC and verification

The energy industries are subjected to the general QA/QC procedures described in section 1.2.3 and in Annex VII QA/QC point sources. The category-specific QA/QC described in section 1.2.3.4 is also valid for Energy Industries.

Some category-specific QA/QC activities were conducted in the following industries:

#### Extraction of oil and natural gas

From 2003 onwards, field specific emission figures reported from the companies are used directly in the emission model. These figures are compared with emissions calculated on the basis of field specific activity data and emission factors.

#### Oil refineries

The CO<sub>2</sub> emissions reported from the refineries are compared with the emissions estimated by Statistics Norway on the basis of activity data and emission factors for the different energy carriers used.

Results from the above studies have so far shown that emission estimates are consistent with the reported figures.

### **3.2.2.7 Category-specific recalculations**

#### **1A1ai Electricity generation**

- Correction of emission data for CO<sub>2</sub> for the years 2019 and 2020.
- The increased emissions of N<sub>2</sub>O for 2012 – 2016 is due to an increase in the energy figures for wood waste.

#### **1A1aiii Heat Plants**

- The amounts of waste in the calculations for the energy statistics were previously higher than there was a basis for. These have therefore been adjusted down, which resulted in lower energy and thus lower emissions.

#### **1A1b Petroleum refining**

- Correction of emission data for CO<sub>2</sub> for one large unit in 2019
- The increased emissions of N<sub>2</sub>O for years 1990-2020 is due to a change in emission factors when energy earlier classified as petroleum coke gas now is classified as blast furnace gas.

#### **1A1ci Manufacture of solid fuels**

- Increased emissions for the years 2007-2018 are due to increased activity data of diesel.

#### **1A1cii Gas**

- Correction of energy related to reported emissions for the entire time series.

### 3.2.2.8 *Category-specific planned improvements*

There are no planned activities this year that will improve the data quality or the documentation for this source category. The project in response to the Saturday Paper in 2018 to reduce the difference between the Reference and the Sectoral approach has been completed to this NIR, see Annex XII and XIII. The work to reduce the statistical difference in the energy balance will continue as part of the continuous improvement work of the energy statistics.

## 3.2.3 Manufacturing industries and construction, 1A2 (Key category for CO<sub>2</sub> and CH<sub>4</sub>)

### 3.2.3.1 *Description*

A description of the general method used for estimating emissions from fuel combustion is given in section 3.2.1 and in Statistics Norway (2013). Emissions from the sector of manufacturing industries and construction include industrial emissions originating to a large extent from the production of raw materials and semi-manufactured goods (e.g., iron and steel, non-ferrous metals, chemicals (e.g., ammonia, methanol, plastics), fertilizers, pulp and paper, mineral industries, food processing industries, building and construction industry). These emissions are related to fuel combustion only, i.e., emissions from use of oil or gas for heating purposes. Consumption of coal as feedstock and reduction medium is not included in this sector but is accounted for under the industrial processes sector (CRF 2).

Emissions from this sector contributed to 6 per cent of the national GHG total in 2021, and 8 per cent of the total emissions from the energy sector. Emissions from the sector decreased by 16 per cent from 1990 to 2021.

According to the approach 2 key category analysis for 1990 and 2021, this sector is, in conjunction with stationary combustion in sectors 1A1 and 1A4, a key category with respect to:

- Emissions of CO<sub>2</sub> from the combustion of liquid fuels, gaseous fuels, and other fuels in level in 1990 and 2021, and in trend
- Emissions of CO<sub>2</sub> from the combustion of solid fuels in level in 1990 and 2021
- Emissions of CH<sub>4</sub> from the combustion of biomass and gaseous fuels in level in 1990 and 2021 and in trend

### 3.2.3.2 *Methodological issues*

A description of the general method used for estimating emissions from fuel combustion is given in section 3.2.1.1. For many plants the emission figures are based on reported figures from the plants to the Norwegian Environment Agency. Indeed, in 2020, these plants accounted for 21% of the CO<sub>2</sub> emissions from the sector (Table 3.3). The general calculation method, amount of fuel combusted multiplied with a fuel specific emissions factor, is valid for both estimates performed by Statistics Norway and emissions reported by the plants to the Norwegian Environment Agency in this sector.

The reported figures are from the mandatory reporting obligation that is a part of the plants permits given by the authorities and from 2005, the emission data are from the emission trading system. The ETS was first a voluntary system, 2005-2007, and then as a part of EU ETS, since 2008. From 1997, there have been different voluntary agreements between national authority and the industry. The agreement from 1997 covered the aluminium producers and included, since 2005, industry not included in the ETS. Industry has, in the different voluntary agreements, committed themselves to reduce their greenhouse gas emissions as a group. As part of the agreements, industry has every year reported detailed AD and emissions to the Norwegian Environment Agency. The voluntary agreement has involved industry i.e., ferroalloy, aluminium, ammonia. From 2013 most of these industries are also part of the ETS.

Figures on energy use are based on data reported from the plants to Statistics Norway. Some of the energy figures used to calculate reported emissions may deviate from the figures in the energy balance. This may, in some cases, cause inaccuracies in IEFs, but generally, this should not be regarded as an important issue.

The guidelines for estimating and reporting emissions are lengthy and in Norwegian, so instead of attaching these to the NIR, URLs are provided in the reference section. Annex VII describes QA/QC performed for plant specific emission data use in the inventory.

#### EU ETS

The guidelines for the EU ETS emission reports (Norwegian Environment Agency 2022) are consistent with the European Union's guidance documents (European Commission). A description of annual normal permit and reporting to the Norwegian Environment Agency is available at the Miljødirektoratet webpage (Miljødirektoratet 2018).

### Ammonia production

Emissions from production of ammonia is reported in this section, as far as emissions from combustion from energy utilization is concerned, while emissions from production of hydrogen from wet gas is reported under process emissions (CRF 2B1), see Section 4.3.1. Emissions included in the inventory are from the plant's annual report to the Norwegian Environment Agency.

The emissions from fuel combustion included in this section are liquid petroleum gas of different composition and CO rich blast furnace gas from a producer of ferroalloy. The activity data and emission factors for the different fuels combusted are shown in section 3.2.1.

### Motorized equipment

Motorized equipment used in manufacturing and construction have been included in this category (CRF 1A2g). Methodologies, activity data and emissions factors are detailed in section 3.2.9.

### 1A2a Iron and steel

The iron and steel industry is a relatively small emission source in Norway, with emissions in the range of 54-84 kilotonnes CO<sub>2</sub> per year in the last ten years. There is no domestic pig iron production. Most of the emissions are from an electrosteel plant and steel product plants. Emissions from the iron and steel industry are mainly energy emissions reported in 1A2a, originating from liquid fuels and from excess gas purchased from adjacent plants. Smaller amounts are from feedstocks as reported in IPPU sector 2C1. On average, around 60 percent of CO<sub>2</sub> energy emissions from the Iron and steel industry arises from combustion of solid fuels - almost exclusively blast furnace gas. Around 30 percent of emissions arise from liquid fuels.

As described in 3.2.1.1 emissions of pollutants from major manufacturing plants (point sources) are available from measurements or other plant-specific calculations. This section describes some specific issues for source category 1A2a Iron and steel that cause variability in the CO<sub>2</sub> IEF time series.

For the Iron and steel industry solid fuels, more than half of CO<sub>2</sub> emissions are directly reported in the period 1990-1996. From 1997 and onwards, all CO<sub>2</sub> emissions are directly reported. There are two point sources that have reported emissions to the NEA from the Iron and steel industry. One plant reported emissions from 1997 to 2010, when it closed.



The second plant has reported emissions from 1990 and onwards. This plant has also reported emissions under the ETS system from 2013.

Concerning reported CO<sub>2</sub> emissions per fuel type, the Iron and steel industry follows the general method from 1990-2007. Then, total CO<sub>2</sub> per plant is entered, and then allocated to fuel type based on the fuel share of the plants calculated emissions (see 3.2.1.1, Eq. 3.3). From 2008 onwards, reported fuel-specific CO<sub>2</sub> emissions is entered. The general method for previous years is associated with a higher degree of uncertainty, and so there is higher degree of uncertainty around fuel specific emissions and larger variability in IEF's in the Iron and steel industry before 2008.

To secure a complete and consistent time series SN subtracts the energy figures from SNs energy balance that are linked to the directly reported CO<sub>2</sub>-emissions from NEA. Sometimes there are inconsistencies between the energy data from NEA and the energy data from SNs energy balance. They are usually small or zero in the later part of the time series but may be larger for some earlier years. In the earlier years there may also have been inconsistencies within reporting to SN, *e.g.*, between energy data in physical and energy terms. Such inconsistencies can give rise to variable IEFs. Large inconsistencies in the IEFs are currently controlled during the QA/QC- work in the production cycle and erroneous figures are corrected.

### **3.2.3.3 Activity data**

Statistics Norway carries out annual surveys on energy use in manufacturing industries, which supply most of the data material for the calculation of combustion emissions in these sectors. The energy use survey covers 90% of the energy use in this sector. For the remaining companies, figures are estimated based on data from the sample together with data on economic turnover, taking into account use of different energy carriers in the same industries and size groups. A change in methodology from 1998 has had minor consequences for the time series, since the energy use is mainly concentrated in a few major plants within the industry, from which data have been collected both in the current and in the earlier method. The data on energy use in manufacturing industries are considered to be of high quality.

Information on use of waste oil and other hazardous waste is also collected through the energy use statistics.

For the construction industry, the figures on use of the different energy carriers are partly taken from the annual sales statistics for petroleum products and are partly projected from earlier surveys; energy data are considered rather uncertain.

In some sectors, auto diesel is mainly used in machinery and off-road vehicles, particularly in mining and construction. This amount of fuel is based on reported consumption of duty-free auto diesel in the manufacturing industries and on reported sales of duty-free auto diesel to construction. The methods for calculating emissions are discussed in section 3.2.9.

#### **3.2.3.4 Emission factors**

Emission factors used in this source category are presented in detail section 3.2.1.3. This section provides information on sectors with variable or deviating implied emission factors in the CRF tables.

##### Iron and steel (1A2a) – solid fuels

The CO<sub>2</sub> IEF for solid fuels in the iron and steel industry shows some variability, particularly in the first part of the time series. Variation in the period with ETS reporting (2013 onwards) is due to measured variation. Variations in the early part of the time series (up to 2005) is generally within  $\pm 10$  per cent of the average IEF, but with some outlying years. This is likely due to inconsistencies between reported data in physical and energy terms. See further discussion in the methodology section 3.2.3.2.

##### Pulp and paper (1A2d) – biomass

The CO<sub>2</sub> IEF for biomass in the pulp and paper industry varies significantly due to changes in the relative amounts of different fuels. The emissions are primarily from black liquor with plant-specific emission factors in the range of 200-250 t CO<sub>2</sub>/TJ and from wood waste with an emission factor of 111 t CO<sub>2</sub>/TJ. In 2013, a large plant using black liquor closed down. This led to a large shift to wood waste in the fuel composition, with a corresponding drop in the IEF.

##### Non-metallic minerals (1A2f) – biomass

The CH<sub>4</sub> IEF for biomass in the minerals industry varies significantly due to changes in the relative amounts of different fuels. The emissions are primarily from charcoal with an emission factor of 200 kg CH<sub>4</sub>/TJ (Table 3.5) and from wood waste with an emission factor of 30 kg CH<sub>4</sub>/TJ (Table 3.6). Most of the fuel consumption is wood waste, but in some years the use of charcoal leads to strong increases in the average IEF, in particular for 2003.

Emissions of CO<sub>2</sub> and N<sub>2</sub>O are similar for the fuels, and the IEFs for these gases vary little among years.

### **3.2.3.5 Uncertainties and time series consistency**

Uncertainties in the activity data and the emission factors in the manufacturing industries and construction are as presented in section 3.2.2.5. A more detailed description is presented in Annex II.

The EU ETS emission estimates are available for all years from 2005. For the time period 1990-2004 there are no data from ETS. Thus, the use of this relatively new data source introduces a degree of inconsistency in the time-series. However, the energy consumption reported under the ETS system is consistent with the energy consumption reported to Statistics Norway for individual plants. In addition, the CO<sub>2</sub> emission estimates are consistent with the emissions reported through the regular permits for land-based industries. These are the data sources used for emissions for the years prior to the introduction of the EU ETS scheme. It is thus assumed that time-series consistency is not significantly affected, and that the emission trend is reliable.

No other time series inconsistencies are known for this sector.

### **3.2.3.6 Category-specific QA/QC and verification**

QC of plant specific data performed by the inventory compilers in the Norwegian Environment Agency before handing over the data to Statistics Norway to be included in the inventory is quite extensive. The QC is described in section 1.2.3 of the NIR and also in Annex VII QA/QC of point sources, section 5 Current QA/QC procedures and data sources. This is an annual QC.

### **3.2.3.7 Category-specific recalculations**

#### **1A2a Iron and steel**

- Revised activity data causes small changes in CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in 2008, 2009, 2010 and 2012.
- Transparency. We discovered an allocation issue for one plant, which had been contributing to high variability in the CO<sub>2</sub> IEF in later years. While the energy from its auto-consumed blast furnace gas had been placed in 1A2A, the CO<sub>2</sub> from this gas were included on 2C1a. It is important to note that there was never any double counting of emissions. Due to the structure of the inventory model, it was not possible to remove this energy from the CRF without removing it from the model altogether. This results in the very small decreases in CH<sub>4</sub> and N<sub>2</sub>O that was

calculated from this gas in the period 2011-2020, on average 20 and 10 kg, respectively.

#### **1A2b Non-ferrous metals**

- Correction of error. CO<sub>2</sub> from the use of petrol coke as fuel are removed from two aluminium plants in the period 2009-2020, as the emissions were already included in the IPPU sector. CO<sub>2</sub> emissions decrease by 8 kt on average.
- Correction of a double counting of light fuel oil AD causes minor decreases in CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in 1997.

#### **1A2b Non-ferrous metals /1A2f Non-metallic minerals**

- Correction of error and allocation. Consumption of petrol coke is reallocated from one plant in 1A2f to a related one in 1A2b in the period 2008-2020. The CO<sub>2</sub> emissions from the petrol coke were already accounted for in the IPPU sector, and so are solely removed from 1A2F. CH<sub>4</sub> and N<sub>2</sub>O are reallocated.

#### **1A2c Chemicals**

- Correction of CO<sub>2</sub>-emissions. Directly reported emissions from one plant were removed due to emissions not corresponding to energy use in the energy data. Emissions from diesel and light fuel oil from this plant are now calculated from energy use in the energy data x EF.
- Correction of double counting of heavy distillate in 1997, resulting in a reduction of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

#### **1A2f Non-metallic minerals**

- Revised activity data for the years 1996 to 2002 resulting in a small change in emissions of CO<sub>2</sub> and N<sub>2</sub>O.
- Correction of AD earlier classified as solid fuels, reallocated as waste and to other fossil fuels. Resulting in a decrease in emissions of CO<sub>2</sub> and an increase of the emissions of CH<sub>4</sub> in the period from 2013-2020.

#### **1A2giii Mining and quarrying**

- Revised activity data in 2010 resulting in a small reduction of CO<sub>2</sub> emissions.

#### **1A2gvii Off-road vehicles and other machinery – Manufacturing and construction**

- The activity data in the energy balance was revised from 2010-2020 due to revised activity data on 1A3c railways.
- Some liquid fuels from 2007-2013 were relocated to 1A1ci Manufacture of solid fuels.

### **3.2.3.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## **3.2.4 Transport – Civil Aviation, 1A3a (Key category for CO<sub>2</sub>)**

### **3.2.4.1 Description**

In 2021, emissions from domestic civil aviation amounted to 7 per cent of the total emissions from transport and 1.7 per cent of the GHG national total. From 1990 to 2019, these emissions increased by 60 per cent due to activity growth. In 2020 and 2021, the activity decreased caused by the coronavirus pandemic and the emissions sank by approximately 30 per cent compared to 2019. Emission fluctuations over time follow the activity growth rates.

According to the approach 2 key category analysis, Civil aviation key categories with respect to CO<sub>2</sub> emissions in level both in 1990 and in 2021. Emissions of CH<sub>4</sub> and N<sub>2</sub>O from this source category are insignificant.

### **3.2.4.2 Methodological issues**

The calculation methodology applied is described in an internal document at Statistics Norway (Thovsen 2017). According to the IPCC Good Practice Guidance the methodology used is Tier 3a based on the detailed methodology in the (EEA 2019). The method is based on Eurocontrol's "Advanced Emission Model"- AEM, combined with data from all aircraft movements to and from Norwegian airports. The method is a "bottom up" calculation of jet kerosene consumption and emissions from aviation based on traffic data, emission factors and energy use factors for aircraft types (kg/km).

These calculations make a distribution basis for the majority (> 95%) of total sales of jet kerosene within the categories of use (domestic/foreign), nationality (Norwegian/foreign companies) and flight phase (LTO/Cruise). The remaining jet kerosene and aviation gasoline is distributed based on assumptions about place of use and nationality in invoice information in sales data from the oil companies. The invoice information also contains information that forms the basis for the economic distribution of all consumption. There is also a distribution of consumption on the type of aircraft (helicopter, jet engine, small aircraft), which is needed to calculate emissions.

All movements below 1000 metres are included in the "Landing Take Off" (LTO) cycle. Movements over 1000 metres are included in the cruise phase. All emissions from international aviation are excluded from national totals and are reported separate (see section 3.7.1).

The calculation method described is only valid from 2010 onwards due to missing traffic data for previous years. The methodology used for the time series 1990 to 2009 is Tier 2 (Skullerud 2014), adjusted by adding some industries that have previously been missing in the activity data, where there is sufficient information to rewrite consumption within these industries. This will have a small effect on the overall distribution between domestic and foreign aviation. No further adjustments have been made to the domestic/foreign distribution.

#### **3.2.4.3 Activity data**

The types of fuel used in aircrafts are both jet kerosene and aviation gasoline. The latter is used mostly in small aircrafts. The total sales of jet kerosene and aviation gasoline are retrieved from the sales statistics of petroleum products and are believed to cover the actual sales of fuel at Norwegian airports. Helicopter data is collected from several Norwegian airlines as the data source with aircraft movements has incomplete helicopter data.

Domestic consumption prior to 1995 is estimated by extrapolation based on domestic kilometers flown and is more uncertain.

#### **3.2.4.4 Emission factors**

The N<sub>2</sub>O and CH<sub>4</sub> emission factors used in the emission inventory for civil aviation are presented in Table 3.12 and Table 3.13 .

The Norwegian Petroleum Industry Association provides CO<sub>2</sub> emission factors for the combustion of jet kerosene and aviation gasoline (Finstad et al. 2002). The CO<sub>2</sub> emission factor used for aviation gasoline is 71.3 tonne CO<sub>2</sub> per TJ (Table 3.4) and has been applied to small aircraft and helicopters. Jet fuel (kerosene) has an emission factor of 73.1 tonne CO<sub>2</sub> per TJ (Table 3.4).

For N<sub>2</sub>O, a default emission factor is used for all aircraft (IPCC) and is valid for both LTO and the cruise phase.

For CH<sub>4</sub> only aggregated emission factors (kg/tonne fuel used) are used in the Norwegian inventory. The emission factors are calculated using total emission divided by total fuel

consumption from a bottom-up analysis based on EEA data. From 2010 onwards, the LTO emission factors for CH<sub>4</sub> are calculated annually in the aviation model. Emission factors prior to 2010 are constant, equal the emission factor in 2010. Studies indicate that only insignificant amounts of methane are emitted during the cruise phase, therefore no methane is calculated for the cruise phase.

**Table 3.12 General emission factors for aviation.**

| Source                           | CH <sub>4</sub> kg/TJ |              | N <sub>2</sub> O kg/TJ           |
|----------------------------------|-----------------------|--------------|----------------------------------|
|                                  | Aviation gasoline     | Jet kerosene | Aviation gasoline / Jet Kerosene |
| <b>Charter/scheduled flights</b> |                       |              |                                  |
| LTO (0-1000 m)                   |                       | <b>5.1</b>   | 2.3                              |
| Cruise (> 1000 m)                |                       |              | 2.3                              |
| <b>Helicopters</b>               |                       |              |                                  |
| LTO (0-1000 m)                   | 43.1                  | 74.2         | 2.3                              |
| Cruise (> 1000 m)                |                       |              | 2.3                              |
| <b>Small aircraft</b>            |                       |              |                                  |
| LTO (0-1000 m)                   | <b>8.9</b>            | <b>9.1</b>   | 2.3                              |
| Cruise (> 1000 m)                |                       |              | 2.3                              |

Source: EEA (2019), Statistics Norway

Bold figures vary, see Table 3.13

**Table 3.13 Time series of variable CH<sub>4</sub> emission factors from the combustion of jet kerosene and aviation gasoline in aviation.**

| LTO (0-1000 m)                   | Fuel              | CH <sub>4</sub> Emission Factor (kg/TJ) |      |      |      |      |      |      |      |
|----------------------------------|-------------------|-----------------------------------------|------|------|------|------|------|------|------|
|                                  |                   | 1990-2010                               | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| <b>Charter/scheduled flights</b> | Jet kerosene      | 4.34                                    | 4.39 | 4.31 | 4.12 | 3.96 | 3.85 | 5.0  | 5.1  |
| <b>Small aircraft</b>            | Aviation gasoline | 9.8                                     | 11.9 | 11.4 | 10.7 | 10.7 | 10.7 | 9.8  | 8.9  |

Source: EEA (2019), Statistics Norway

### 3.2.4.5 Uncertainties and time series consistency

#### Activity data

The uncertainty in the activity data for civil aviation is estimated to be  $\pm 20\%$  of the mean primarily due to the difficulty in separating domestic emissions from emissions from fuel used in international transport (Rypdal & Zhang 2000). However, the emission model used from 2010 onwards is assumed to have lower uncertainty because of more accurate

activity data. As described above, data before 1995 are more uncertain than for later years. This may also, to a certain degree, affect the time series consistency.

#### Emission factors

The uncertainty in the CO<sub>2</sub> emission factors is  $\pm 3\%$ . The uncertainty in the CH<sub>4</sub> and N<sub>2</sub>O emission factors lies below and above the mean by a factor of 2 and 3, respectively.

#### **3.2.4.6 Category-specific QA/QC and verification**

Chapter 1.2.3 gives a description of the general QA/QC procedure.

In 2018, a methodology improvement was made in the emission calculations for civil aviation (Thovsen 2017). According to the IPCC Good Practice Guidance the methodology used is Tier 3 based on the detailed methodology in EEA (2019). This methodology allows estimation of emissions and fuel consumption for different types of aircrafts according to aircraft movements. The data are annually updated with emission factors and fuel consumption factors for new aircrafts in domestic and international traffic.

#### **3.2.4.7 Category-specific recalculations**

Activity data from respondents has been updated, and this resulted in higher domestic and international activity and emissions for the years 2019-2020.

#### **3.2.4.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **3.2.5 Transport – Road Transportation, 1A3b (Key category for CO<sub>2</sub>)**

#### **3.2.5.1 Description**

Road traffic accounted for 71 per cent of the total GHG emissions from transport and for 18 per cent of the national GHG total in 2021.

Emissions from road traffic reached a maximum in 2015, with an increase of 38 per cent over 1990. Since 2015, the emissions have been reduced by 15 per cent, mainly due to use of biofuels, but increasingly due to the introduction of electric vehicles. Net increase for the inventory period 1990-2021 was 17 per cent.

According to the approach 2 key category analysis, this sector is a key category with respect to emissions of CO<sub>2</sub> in level in 1990 and 2021, and trend.



Since 1990, emissions from **passenger cars** (PCs) have decreased by 18 per cent, while vehicle kilometers for PC have increased by 54 per cent and the number of PCs has grown by 79 per cent. During the period the vehicles have become more fuel efficient. There was a strong shift from petrol to diesel driven passenger cars after 2000, with diesel levels over 70 per cent from 2007 due to the CO<sub>2</sub> differentiated tax on new passenger cars implemented that year. However, from 2011 the shift in sales has been back to petrol and to electric vehicles. In addition, the consumption of biodiesel and bioethanol has increased since 2006 reaching a peak in 2017, see Figure 3-11, and hence contributed to the CO<sub>2</sub> emission decrease. Since then, the biofuel fraction has varied between 12 and 16 per cent of total road fuels by volume. The biofuel fraction in 2021 was 14 per cent.

Emissions from **light commercial vehicles** (LCV) and **heavy-duty vehicles** (HDV) increased by 101 per cent and 81 per cent respectively, during the period 1990-2021. Use of biofuels has had a larger impact on these vehicle classes than for passenger cars because the biofuel blend-in rate has been larger in auto diesel than in gasoline.

PCs' contribution to total CO<sub>2</sub> emissions from road traffic decreased from 68 per cent in 1990 to 48 per cent in 2021. Light commercial vehicles (LCV) and heavy-duty vehicles (HDV) increased their contribution to total emissions for road traffic from 10 to 17 per cent, and 21 to 33 per cent, respectively, from 1990 to 2021.

The increase in LCV's share of the total emissions from road traffic illustrates the increase of goods transport since 1990 as a consequence of increased trade and consumption of goods due to economic growth.

HDVs consist of trucks and buses but it is specifically trucks that are responsible for the increase of emissions from 1990.

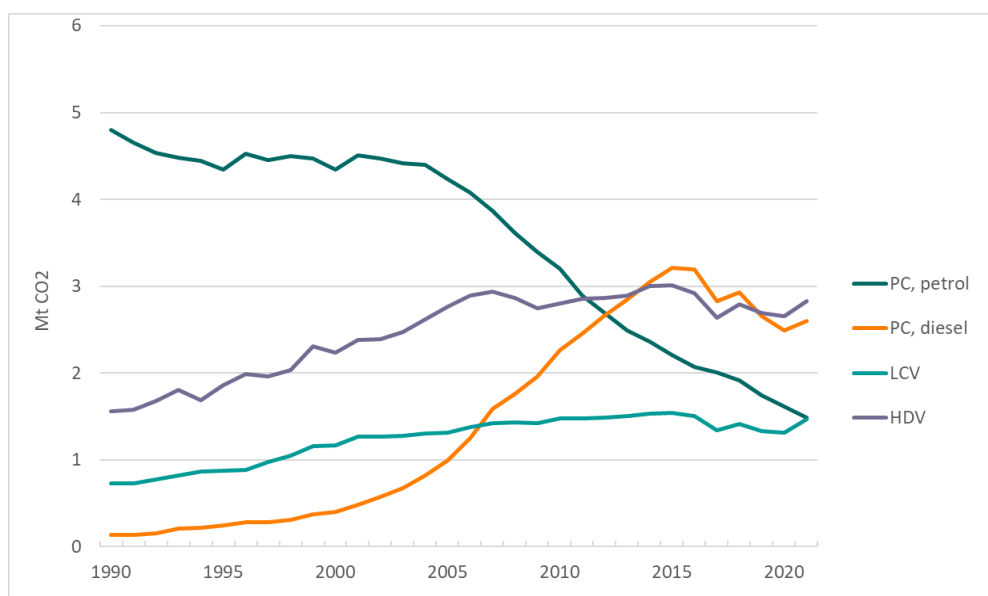


Figure 3-6. Emissions of CO<sub>2</sub>. PC petrol and diesel, LCV and HDV. 1990-2021. Million tonne CO<sub>2</sub> equivalents. Source: Statistics Norway/Norwegian Environment Agency

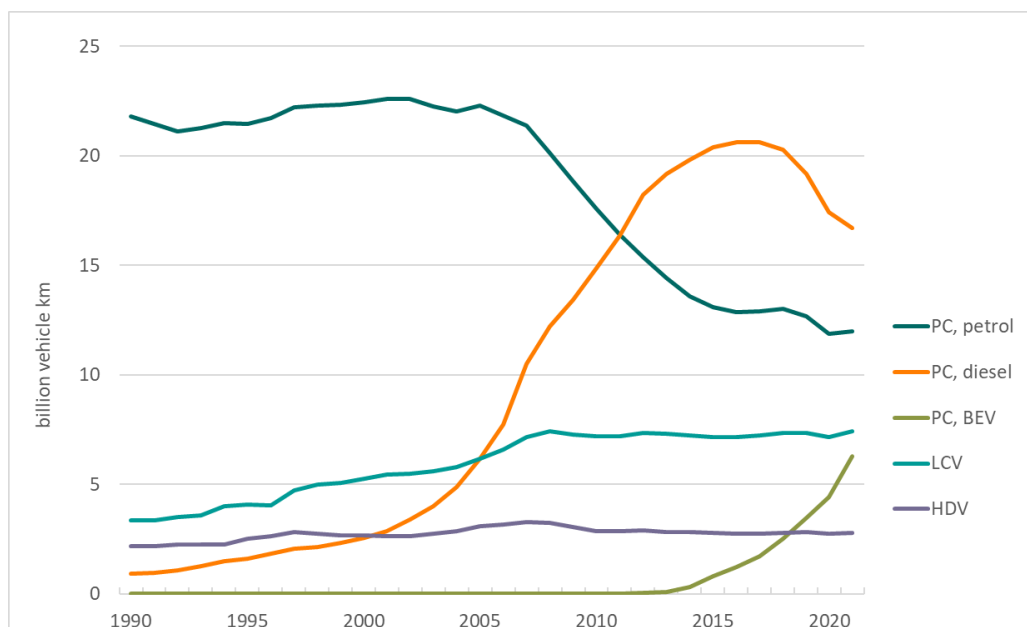


Figure 3-7. Vehicle kilometer. PC petrol and diesel, LCV and HDV. 1990-2021. BEV = Battery electric vehicles. Source: Statistics Norway/Norwegian Environment Agency

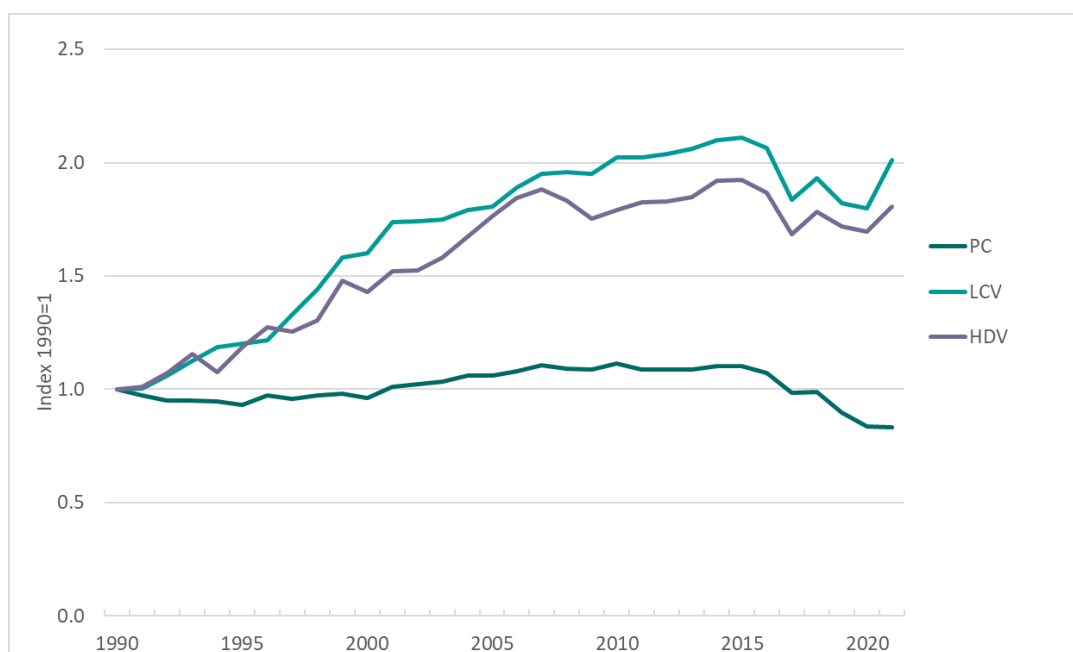


Figure 3-8. Relative change to 1990 in total CO<sub>2</sub> emissions from PC, LCV and HDV. Index 1990=1.

Source: Statistics Norway/Norwegian Environment Agency

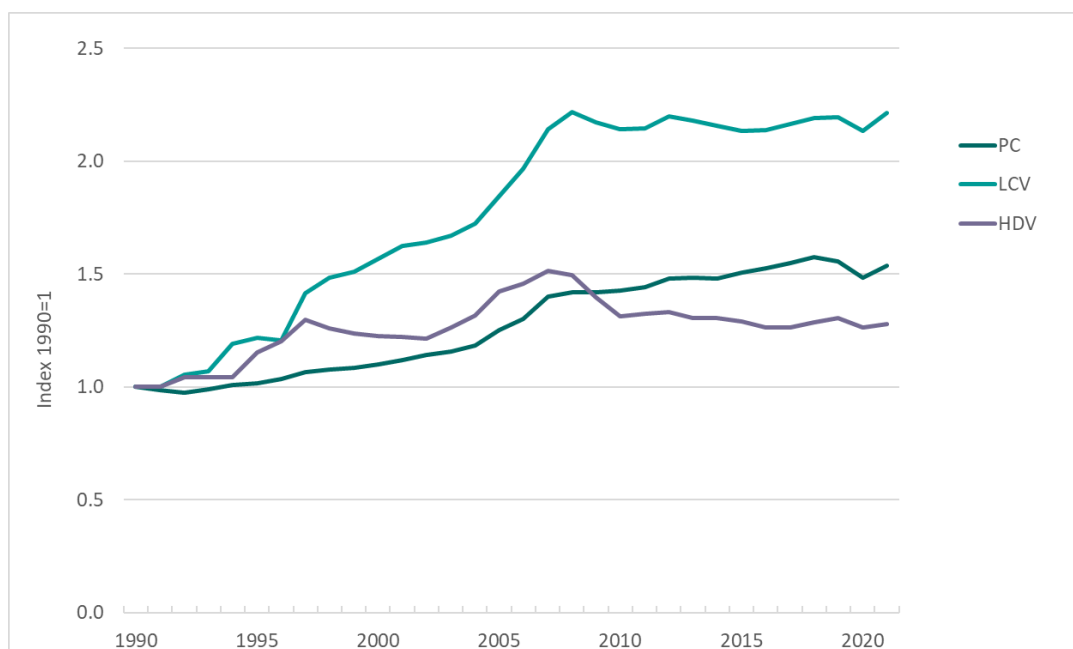


Figure 3-9. Relative change to 1990 in total vehicle km. PC, LCV, HDV. Index 1990=1

Source: Statistics Norway/Norwegian Environment Agency

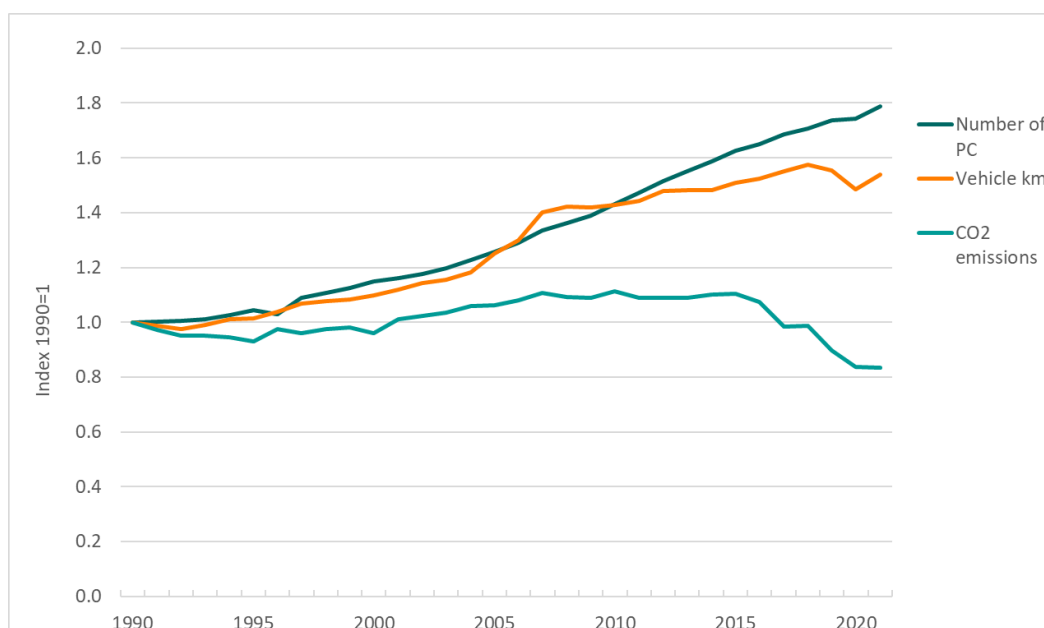


Figure 3-10. Relative change to 1990 in number of passenger cars, CO<sub>2</sub> emissions and vehicle kilometers. Index 1990=1. Source: Statistics Norway/Norwegian Environment Agency

### 3.2.5.2 Methodological issues

Total emissions of CO<sub>2</sub> have been estimated directly from total consumption of each fuel. The consumption of gasoline, including bioethanol, for road traffic has been estimated as total sales minus consumption for other uses, i.e., a top-down approach. Other uses for gasoline are e.g., small boats, snow mobiles and motorized equipment. For auto diesel, the total consumption in road traffic is all auto diesel, including biodiesel, charged with auto diesel tax. Other uses of auto diesel, excluding biodiesel are e.g., motorized equipment in agriculture and construction. Consumption of compressed natural gas (CNG) is based on a survey reported by suppliers of CNG. Consumption of LPG is estimated based on figures from the sales statistics on petroleum products and figures from “Drivkraft Norge”, a Norwegian association for the fuel and energy sector in Norway.

Emissions of CH<sub>4</sub> and N<sub>2</sub>O are estimated by the HBEFA model (INFRAS 2022). The model uses a mileage approach:

$$\text{Emissions} = \text{mileage} * \text{emission per km}$$

The model results are used directly, without any adjustment for discrepancies between estimated consumption in the model and registered fuel sale.

The HBEFA model provides emission factors and possibilities for calculating emissions for segments and sub-segments for six vehicle classes: passenger cars, light commercial

vehicles, heavy commercial vehicles, urban buses, coaches, and motorcycles (including mopeds). The segments are based on technology. Segments for motorcycles also include engine volumes, while segments for heavy commercial vehicles, urban buses and coaches includes total weight, and light commercial vehicles include gross weight. The segments are further disaggregated into sub segments based on emission concepts (e.g., Euro-1 – Euro-6). The segments used for Norway in the HBEFA model are presented in [Table 3.14](#).

The model combines the number of vehicles within each segment with driving lengths for the same segments to produce annual national mileage per sub segment. For heavy goods vehicles, the vehicle number is corrected for vehicles driving with trailers, and the driving is split into three load classes (empty, half loaded and fully loaded).

The annual national mileage is split between shares driven in different traffic situations. The traffic situations are a combination of area (urban/rural), road type (e.g., trunk road and access road), speed limit and level of service (free flow, heavy, saturated, and stop and go). The traffic situations are further disaggregated by gradients, where the amount of driving on roads with slopes ranging from -6% to 6% is specified for each traffic situation.

Hot emission factors are provided on the disaggregated level of sub segments and traffic situations with different gradients, and emissions are estimated after these steps of disaggregation.

The HBEFA model provides emission factors for cold emissions and evaporative emissions (soak, running losses and diurnal), in addition to hot emission factors. In order to calculate cold and evaporative emissions, information on diurnal variation in curves of traffic, trip length distributions, parking time distributions and driving behaviour distributions must be provided, in addition to variation in mean air temperature and humidity.

| Table 3.14 Segments used for Norway in the HBEFA. |                          |           |                        |                             |
|---------------------------------------------------|--------------------------|-----------|------------------------|-----------------------------|
| Vehicle class                                     | Segment                  | Fuel type | Segment split based on | Engine volume/ weight class |
| Passenger car                                     | PC petrol                | Petrol    | -                      | All engine volumes          |
|                                                   | PC PHEV petrol           | Petrol    | -                      | All engine volumes          |
|                                                   | PC diesel                | Diesel    | -                      | All engine volumes          |
|                                                   | PC PHEV diesel           | Diesel    | -                      | All engine volumes          |
|                                                   | PC LPG                   | LPG       | -                      | All engine volumes          |
|                                                   | PC BEV                   | Electric  | -                      | All engine volumes          |
| Light commercial vehicles                         | LCV petrol M+N1-I        | Petrol    | Tare weight            | < 1305 kilos                |
|                                                   | LCV petrol N1-II         | Petrol    | Tare weight            | >= 1305-1760 kilos          |
|                                                   | LCV petrol N1-III        | Petrol    | Tare weight            | >= 1760-3859 kilos          |
|                                                   | LCV diesel M+N1-I        | Diesel    | Tare weight            | < 1305 kilos                |
|                                                   | LCV diesel N1-II         | Diesel    | Tare weight            | >= 1305-1760 kilos          |
|                                                   | LCV diesel N1-III        | Diesel    | Tare weight            | >= 1760-3859 kilos          |
|                                                   | LCV BEV M+N1-I           | Electric  | Tare weight            | < 1305 kilos                |
|                                                   | LCV BEV N1-II            | Electric  | Tare weight            | >= 1305-1760 kilos          |
|                                                   | LCV BEV N1-III           | Electric  | Tare weight            | >= 1760-3859 kilos          |
| Heavy goods vehicles                              | RT petrol                | Petrol    | -                      | All gross weights           |
|                                                   | RigidTruck <7,5t         | Diesel    | Gross weight           | <= 7.5 tonnes               |
|                                                   | RigidTruck 7,5-12t       | Diesel    | Gross weight           | > 7.5 - 12 tonnes           |
|                                                   | RigidTruck >12-14t       | Diesel    | Gross weight           | > 12 - 14 tonnes            |
|                                                   | RigidTruck >14-20t       | Diesel    | Gross weight           | > 14 - 20 tonnes            |
|                                                   | RigidTruck >20-26t       | Diesel    | Gross weight           | > 20 - 26 tonnes            |
|                                                   | RigidTruck >26-28t       | Diesel    | Gross weight           | > 26 - 28 tonnes            |
|                                                   | RigidTruck >28-32t       | Diesel    | Gross weight           | > 28 - 32 tonnes            |
|                                                   | RigidTruck >32t          | Diesel    | Gross weight           | > 32 tonnes                 |
|                                                   | RigidTruck BEV <7,5t     | Electric  | Gross weight           | <= 7.5 tonnes               |
|                                                   | RigidTruck BEV 7,5-12t   | Electric  | Gross weight           | > 7.5 - 12 tonnes           |
|                                                   | RigidTruck BEV >12       | Electric  | Gross weight           | > 12 tonnes                 |
|                                                   | Tractor for AT <=7,5t    | Diesel    | Gross weight           | <= 7.5 tonnes               |
|                                                   | Tractor for AT>7,5-14t   | Diesel    | Gross weight           | > 7,5 - 14 tonnes           |
|                                                   | Tractor for AT>14-20t    | Diesel    | Gross weight           | > 14 - 20 tonnes            |
|                                                   | Tractor for AT>20-28t    | Diesel    | Gross weight           | > 20 - 28 tonnes            |
|                                                   | Tractor for AT >34-40t   | Diesel    | Gross weight           | > 34 - 40 tonnes            |
|                                                   | Tractor for AT >40-50t   | Diesel    | Gross weight           | > 40 - 50 tonnes            |
|                                                   | Tractor for AT >50-60t   | Diesel    | Gross weight           | > 50 - 60 tonnes            |
|                                                   | Tractor for AT BEV       | Electric  | -                      | All gross weights           |
| Coach                                             | Coach Std <=18t          | Diesel    | Gross weight           | <= 18 tonnes                |
|                                                   | Coach 3-Axes >18t        | Diesel    | Gross weight           | > 18 tonnes                 |
|                                                   | Coach Electric Std <=18t | Electric  | Gross weight           | <= 18 tonnes                |

|                               |                            |          |               |                 |
|-------------------------------|----------------------------|----------|---------------|-----------------|
|                               | Coach Electric 3-Axes >18t | Electric | Gross weight  | > 18 tonnes     |
| <b>Urban bus</b>              | Ubus Midi <=15t            | Diesel   | Gross weight  | <= 15 tonnes    |
|                               | Ubus Std >15-18t           | Diesel   | Gross weight  | >15 - 18 tonnes |
|                               | Ubus Artic >18t            | Diesel   | Gross weight  | > 18 tonnes     |
|                               | Ubus CNG Std >15-18t       | CNG      | Gross weight  | >15 - 18 tonnes |
|                               | Ubus CNG Artic >18t        | CNG      | Gross weight  | > 18 tonnes     |
|                               | Ubus Electric Midi <=15t   | Electric | Gross weight  | <= 15 tonnes    |
|                               | Ubus Electric Std >15-18t  | Electric | Gross weight  | >15 - 18 tonnes |
|                               | Ubus Electric Artic >18t   | Electric | Gross weight  | > 18 tonnes     |
| <b>Motorcycles and mopeds</b> | Moped <=50cc (v<50kmh)     | Petrol   | Engine volume | <= 50 cc        |
|                               | MC 2S <=250cc              | Petrol   | Engine volume | <= 250 cc       |
|                               | MC 4S <=250cc              | Petrol   | Engine volume | <= 250 cc       |
|                               | MC 4S > 250cc              | Petrol   | Engine volume | > 250 cc        |

Source: Statistics Norway

### 3.2.5.3 Activity data

All activity data are, as far as possible, updated for every year of the inventory. Data are taken primarily from official registers, public statistics, and surveys. However, some of the data are based on assumptions. Many of the data sources are less comprehensive for the earliest years in the inventory. The sources of activity data are listed below:

- *Total fuel consumption:* The total amounts of fuels consumed are corrected for off-road use (in boats, snow scooters, motorized equipment, etc.). These corrections are estimated either from assumptions about the number of units, annual operation time, and specific fuel consumption, or from assumptions about and investigations of the fraction of consumption used off-road in each sector. Statistics Norway's sales statistics for petroleum products supplies the data for total fuel consumption (Statistics Norway Annually-b). See Figure 3-11, which shows the fuel consumption split between fossil petrol, diesel, and biofuels (biodiesel and bioethanol). Consumption of biofuels is included in the inventory from 2004. In 2021, the share of biofuel in fuel sales were 13 per cent.
- *Number of vehicles:* The number of vehicles in the various categories and age groups is taken from the statistics on registered vehicles, which receives data from the official register of the Norwegian Directorate of Public Roads. The model input is number of vehicles per vehicle class for each inventory year, and the share of vehicles for any given combination of segment. This data is combined with information on the introduction of technology classes to provide number of vehicles within each sub segment. The information on introduction of technology classes is, for recent years, based on

information from the official register of the Norwegian Directorate of Public Roads and on legislation for the years in which the information in the register is insufficient.

- The HBEFA model distinguishes between two types of buses: urban buses mainly used for urban driving, and coaches, mainly used for rural and motorway driving. Due to lack of specific information to make this split in the national vehicle register, the distinction between urban buses and coaches are based on a methodology used in Sweden (Swedish Environmental Protection Agency 2011), where the split is made based on the ratio  $p/w$ . Here,  $p$  is equal to the maximum allowed number of passengers (number of seats plus number of allowed standing passengers), and  $w$  is equal to the gross vehicle weight. These data are available in the national vehicle register. Buses with a  $p/w$ -value above 3.75 are classified as urban buses, whereas buses with a  $p/w$ -value below 3.75 are classified as coaches.
- *Average annual mileage*: Mileages for passenger cars, light commercial vehicles, heavy goods vehicles, coaches, and urban buses are, from 2005 onwards, based on odometer readings taken during annual or biannual roadworthiness tests. The readings are collected by the Directorate of Public Roads and further processed by Statistics Norway. For earlier years, most figures are determined from surveys by Statistics Norway or the Institute of Transport Economics. In some instances, assumptions are needed.
- The statistics on number of vehicles depict the vehicle fleet per December 31<sup>st</sup> of the inventory year, while the statistics on mileages represents annual driving for the entire year, including vehicles that have been scrapped or in other ways been in the vehicle fleet for only parts of the inventory year. To adjust for this discrepancy, mean annual driving lengths for each vehicle category have been adjusted upwards in such a way that the totals correspond to the total annual traffic activity from the statistics on annual driving lengths.
- The average annual mileages vary as a function of age, with older vehicles generally driving shorter annual distances than newer vehicles. The correction of driving as a function of vehicle age is based on odometer readings taken during the roadworthiness test. The functions are calculated as the mean of several years, and the same correction curve is used for all years.
- Motorcycles and mopeds are not subject to roadworthiness tests in Norway. Average annual mileages are collected from an annual report on transport volumes in Norway from the Institute of Transport Economics. Due to lack of data, corrections of annual mileage as a function of age for motor cycles and mopeds are taken from a Swedish survey (Björketun & Nilsson 2007) under the assumption that annual mileage as a function of age are comparable in Norway and Sweden.
- *Load data* are taken from the Road goods transport survey (Statistics Norway 2010b).



- *Transformation patterns* are calculated using information from Statistics Norway' Road goods transport survey on use of trailers and trailer size (Statistics Norway 2010b).
- *Traffic situations*: The Directorate of Public Roads has data on the annual number of vehicle-kilometres driven on national and county roads. Data are allocated by speed limits, road type, area type (urban/ rural), road gradients and vehicle size (small/ large). Traffic on municipal roads is estimated by Statistics Norway based on road lengths, detailed population data, traffic on adjoining roads, etc. The HBEFA model has emission factors for different situations of traffic flow (free flow, heavy traffic, saturated traffic, stop and go and heavy stop and go). Assumptions have been made as to this distribution for the different combinations of area type, road type and speed limits for Norway.
- *Ambient conditions* (air temperature and humidity) are included in the model to calculate cold and evaporative emissions. An average of five larger Norwegian cities has been used for spring, summer, autumn, and winter separately. Data are based on measurements from the Norwegian meteorological institute.
- *Trip length and parking time distributions* are calculated from the Norwegian Travel survey (Vibe 1993). The distributions are given on hourly basis.

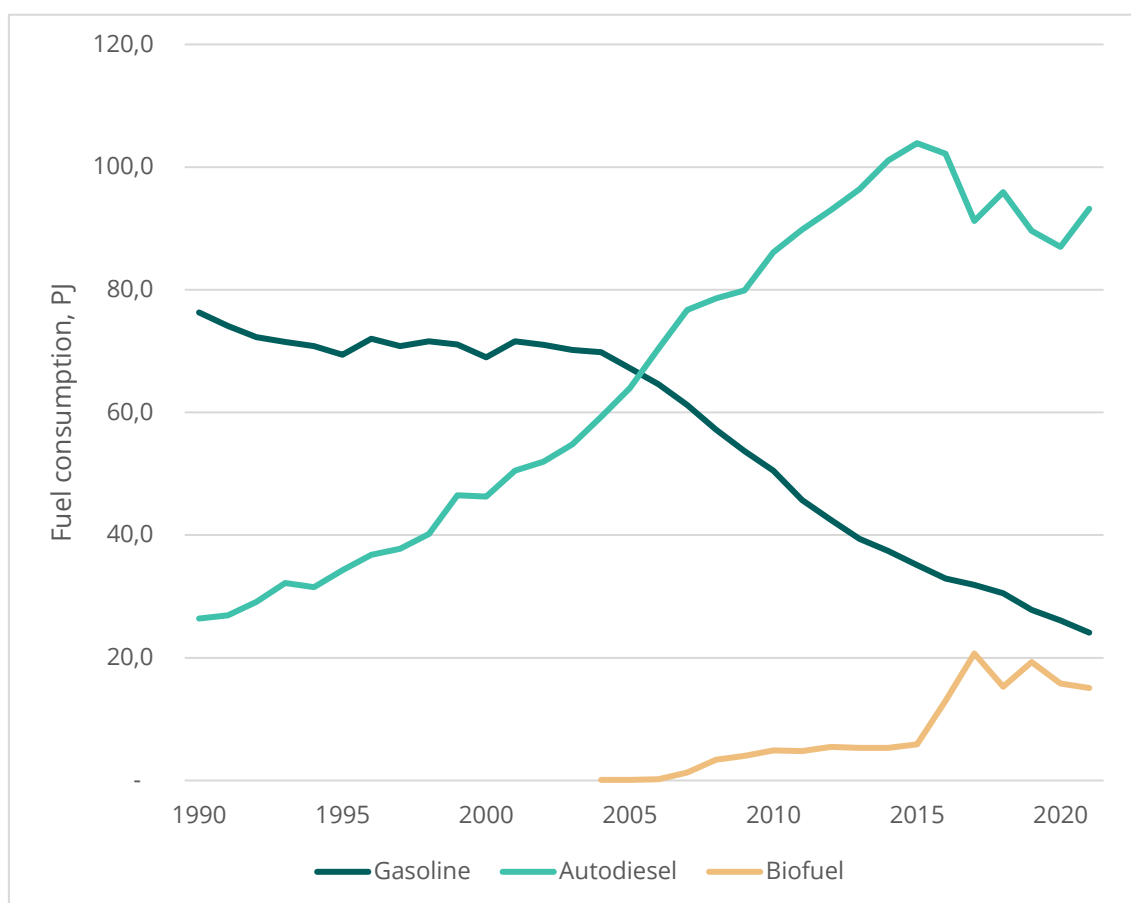


Figure 3-11. Consumption of gasoline, auto diesel and biofuel for road transportation. 1990-2021. PJ Source: Statistics Norway

### 3.2.5.4 Emission factors

Emission factors (except CO<sub>2</sub>) are taken from the Handbook of Emission Factors (HBEFA; (INFRAS 2022)). Factors are given as emission per vehicle kilometres for detailed combinations of subsegments and traffic situations.

#### CO<sub>2</sub>

Emission factors for CO<sub>2</sub> are given by fuel type in Table 3.4. The factor for fossil motor gasoline is 71.3 tonne CO<sub>2</sub> per TJ, while the factor for auto diesel is 73.55 tonne CO<sub>2</sub> per TJ. The CO<sub>2</sub> factors used for ethanol is 71.27 tonne CO<sub>2</sub> per TJ and for biodiesel 77.45 tonne CO<sub>2</sub> per TJ.

Table 3.15 shows average CO<sub>2</sub> emissions per year and vehicle category, as calculated using HBEFA 4.2.

| <b>Table 3.15 Average CO<sub>2</sub> emission from different vehicle classes, including cold start emissions and evaporation. 1990-2021. Unit: g/km.</b> |                             |                           |                     |             |                             |                           |                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|---------------------------|---------------------|-------------|-----------------------------|---------------------------|---------------------|
|                                                                                                                                                          | Motor gasoline              |                           |                     |             | Auto diesel                 |                           |                     |
|                                                                                                                                                          | Passenger cars <sup>1</sup> | Light commercial vehicles | Heavy duty vehicles | Motorcycles | Passenger cars <sup>1</sup> | Light commercial vehicles | Heavy duty vehicles |
| <b>1990</b>                                                                                                                                              | 191                         | 200                       | 557                 | 77          | 163                         | 233                       | 829                 |
| <b>1995</b>                                                                                                                                              | 189                         | 202                       | 558                 | 86          | 163                         | 235                       | 816                 |
| <b>2000</b>                                                                                                                                              | 184                         | 201                       | 557                 | 98          | 159                         | 231                       | 859                 |
| <b>2005</b>                                                                                                                                              | 178                         | 187                       | 556                 | 95          | 159                         | 214                       | 895                 |
| <b>2010</b>                                                                                                                                              | 173                         | 180                       | 561                 | 95          | 150                         | 205                       | 969                 |
| <b>2011</b>                                                                                                                                              | 171                         | 179                       | 561                 | 95          | 148                         | 204                       | 976                 |
| <b>2012</b>                                                                                                                                              | 169                         | 179                       | 561                 | 95          | 146                         | 203                       | 981                 |
| <b>2013</b>                                                                                                                                              | 166                         | 180                       | 561                 | 95          | 145                         | 202                       | 987                 |
| <b>2014</b>                                                                                                                                              | 162                         | 180                       | 561                 | 96          | 145                         | 200                       | 993                 |
| <b>2015</b>                                                                                                                                              | 158                         | 179                       | 557                 | 97          | 145                         | 199                       | 985                 |
| <b>2016</b>                                                                                                                                              | 155                         | 179                       | 557                 | 97          | 145                         | 197                       | 991                 |
| <b>2017</b>                                                                                                                                              | 152                         | 179                       | 557                 | 98          | 145                         | 195                       | 1002                |
| <b>2018</b>                                                                                                                                              | 149                         | 177                       | 557                 | 98          | 146                         | 194                       | 1004                |
| <b>2019</b>                                                                                                                                              | 148                         | 176                       | 557                 | 97          | 146                         | 191                       | 1001                |
| <b>2020</b>                                                                                                                                              | 146                         | 174                       | 557                 | 97          | 146                         | 189                       | 1008                |
| <b>2021</b>                                                                                                                                              | 144                         | 175                       | 557                 | 97          | 146                         | 189                       | 1004                |

Source: The Norwegian road emission model that is operated by Statistics Norway

<sup>1</sup> Excluding plugin hybrid vehicles

## CH<sub>4</sub> and N<sub>2</sub>O

| <b>Table 3.16 General CH<sub>4</sub> and N<sub>2</sub>O emission factors from use of natural gas and LPG for passenger cars and heavy-duty vehicles.</b> |             |                       |                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------------|------------------------|
| Source                                                                                                                                                   | Fuel        | CH <sub>4</sub> kg/TJ | N <sub>2</sub> O kg/TJ |
| <b>Passenger cars</b>                                                                                                                                    | LPG         | 24.6                  | 0.90                   |
| <b>Heavy duty vehicles</b>                                                                                                                               | Natural gas | 409.3                 | 5.36                   |

Source: HBEFA (INFRAS 2022), COPERT 5, IPCC (2006)

| <b>Table 3.17 Average CH<sub>4</sub> emission factors from road traffic including cold start emissions and evaporation. 1990-2021. Unit: g/km.</b> |                             |                           |                     |             |                             |                           |                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|---------------------------|---------------------|-------------|-----------------------------|---------------------------|---------------------|
|                                                                                                                                                    | Motor gasoline              |                           |                     |             | Auto diesel                 |                           |                     |
|                                                                                                                                                    | Passenger cars <sup>1</sup> | Other light duty vehicles | Heavy duty vehicles | Motorcycles | Passenger cars <sup>1</sup> | Other light duty vehicles | Heavy duty vehicles |
| <b>1990</b>                                                                                                                                        | 0.1193                      | 0.1227                    | 0.1566              | 0.2107      | 0.0069                      | 0.0053                    | 0.0308              |
| <b>1995</b>                                                                                                                                        | 0.1193                      | 0.1065                    | 0.1566              | 0.1834      | 0.0052                      | 0.0049                    | 0.0268              |
| <b>2000</b>                                                                                                                                        | 0.1193                      | 0.0797                    | 0.1567              | 0.1990      | 0.0039                      | 0.0034                    | 0.0158              |
| <b>2005</b>                                                                                                                                        | 0.1193                      | 0.0556                    | 0.1568              | 0.3002      | 0.0029                      | 0.0024                    | 0.0113              |
| <b>2010</b>                                                                                                                                        | 0.1193                      | 0.0417                    | 0.1558              | 0.2813      | 0.0025                      | 0.0017                    | 0.0065              |
| <b>2011</b>                                                                                                                                        | 0.1193                      | 0.0408                    | 0.1558              | 0.2794      | 0.0028                      | 0.0019                    | 0.0055              |
| <b>2012</b>                                                                                                                                        | 0.1193                      | 0.0398                    | 0.1558              | 0.2761      | 0.0030                      | 0.0021                    | 0.0049              |
| <b>2013</b>                                                                                                                                        | 0.1193                      | 0.0391                    | 0.1558              | 0.2714      | 0.0033                      | 0.0025                    | 0.0044              |
| <b>2014</b>                                                                                                                                        | 0.1193                      | 0.0385                    | 0.1558              | 0.2662      | 0.0035                      | 0.0028                    | 0.0037              |
| <b>2015</b>                                                                                                                                        | 0.1193                      | 0.0381                    | 0.1563              | 0.2591      | 0.0039                      | 0.0031                    | 0.0032              |
| <b>2016</b>                                                                                                                                        | 0.1193                      | 0.0378                    | 0.1563              | 0.2523      | 0.0046                      | 0.0036                    | 0.0028              |
| <b>2017</b>                                                                                                                                        | 0.1193                      | 0.0365                    | 0.1563              | 0.2440      | 0.0052                      | 0.0042                    | 0.0024              |
| <b>2018</b>                                                                                                                                        | 0.1193                      | 0.0354                    | 0.1563              | 0.2321      | 0.0056                      | 0.0048                    | 0.0021              |
| <b>2019</b>                                                                                                                                        | 0.1193                      | 0.0348                    | 0.1563              | 0.2210      | 0.0059                      | 0.0057                    | 0.0018              |
| <b>2020</b>                                                                                                                                        | 0.1193                      | 0.0345                    | 0.1563              | 0.2093      | 0.0061                      | 0.0068                    | 0.0018              |
| <b>2021</b>                                                                                                                                        | 0.1193                      | 0.0344                    | 0.1563              | 0.1973      | 0.0062                      | 0.0075                    | 0.0016              |

Source: The Norwegian road emission model that is operated by Statistics Norway

<sup>1</sup> Excluding plugin hybrid vehicles

| <b>Table 3.18 Average N<sub>2</sub>O emission factors from road traffic including cold start emissions and evaporation. 1990-2021. Unit: g/km.</b> |                             |                           |                     |             |                             |                           |                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|---------------------------|---------------------|-------------|-----------------------------|---------------------------|---------------------|
|                                                                                                                                                    | Motor gasoline              |                           |                     |             | Auto diesel                 |                           |                     |
|                                                                                                                                                    | Passenger cars <sup>1</sup> | Other light duty vehicles | Heavy duty vehicles | Motorcycles | Passenger cars <sup>1</sup> | Other light duty vehicles | Heavy duty vehicles |
| <b>1990</b>                                                                                                                                        | 0.0072                      | 0.0068                    | 0.0071              | 0.0013      | 0.0000                      | 0.0000                    | 0.0088              |
| <b>1995</b>                                                                                                                                        | 0.0093                      | 0.0083                    | 0.0071              | 0.0014      | 0.0002                      | 0.0004                    | 0.0087              |
| <b>2000</b>                                                                                                                                        | 0.0098                      | 0.0113                    | 0.0071              | 0.0016      | 0.0026                      | 0.0030                    | 0.0090              |
| <b>2005</b>                                                                                                                                        | 0.0052                      | 0.0104                    | 0.0071              | 0.0015      | 0.0039                      | 0.0040                    | 0.0077              |
| <b>2010</b>                                                                                                                                        | 0.0042                      | 0.0078                    | 0.0071              | 0.0016      | 0.0046                      | 0.0044                    | 0.0153              |
| <b>2011</b>                                                                                                                                        | 0.0038                      | 0.0074                    | 0.0071              | 0.0016      | 0.0049                      | 0.0046                    | 0.0204              |
| <b>2012</b>                                                                                                                                        | 0.0034                      | 0.0069                    | 0.0071              | 0.0016      | 0.0052                      | 0.0048                    | 0.0243              |
| <b>2013</b>                                                                                                                                        | 0.0029                      | 0.0063                    | 0.0071              | 0.0016      | 0.0055                      | 0.0050                    | 0.0269              |
| <b>2014</b>                                                                                                                                        | 0.0024                      | 0.0058                    | 0.0071              | 0.0016      | 0.0057                      | 0.0052                    | 0.0314              |
| <b>2015</b>                                                                                                                                        | 0.0021                      | 0.0053                    | 0.0071              | 0.0016      | 0.0059                      | 0.0055                    | 0.0347              |
| <b>2016</b>                                                                                                                                        | 0.0018                      | 0.0048                    | 0.0071              | 0.0016      | 0.0063                      | 0.0059                    | 0.0377              |
| <b>2017</b>                                                                                                                                        | 0.0015                      | 0.0042                    | 0.0071              | 0.0016      | 0.0066                      | 0.0065                    | 0.0399              |
| <b>2018</b>                                                                                                                                        | 0.0013                      | 0.0037                    | 0.0071              | 0.0016      | 0.0069                      | 0.0071                    | 0.0416              |
| <b>2019</b>                                                                                                                                        | 0.0012                      | 0.0034                    | 0.0071              | 0.0016      | 0.0071                      | 0.0077                    | 0.0430              |
| <b>2020</b>                                                                                                                                        | 0.0010                      | 0.0030                    | 0.0071              | 0.0017      | 0.0073                      | 0.0083                    | 0.0436              |
| <b>2021</b>                                                                                                                                        | 0.0010                      | 0.0029                    | 0.0071              | 0.0017      | 0.0074                      | 0.0088                    | 0.0452              |

Source: The Norwegian road emission model that is operated by Statistics Norway

<sup>1</sup> Excluding plugin hybrid vehicles

N<sub>2</sub>O from gasoline fuelled PC: The N<sub>2</sub>O EF in the HBEFA is from the COPERT IV model. In addition to the "normal" reduction of the EF according to the Euro-classes, the N<sub>2</sub>O EF is influenced by the sulphur content. Indeed, a lower sulphur content of gasoline leads to a reduced deactivation of the catalyst and reduced N<sub>2</sub>O formation. This finding is backed up by several international peer-reviewed papers.

The sulphur content in petrol was 0.3% in 2004 and 0.05% in 2005. This sharp drop in sulphur content explains the decrease in N<sub>2</sub>O EF between 2004 and 2005. Similar development in the N<sub>2</sub>O EF can also be seen in countries, which also use the HBEFA model, e.g., Switzerland and Sweden.

### CH<sub>4</sub> and N<sub>2</sub>O from biofuels/biomass in road transport

In the inventory, the same emission factors for CH<sub>4</sub> and N<sub>2</sub>O are used for biofuels as for corresponding fossil fuels. Thus, the average IEF for biomass in road transport is a function of the fractions of ethanol and biodiesel in the biofuel mix. Initially, the small biofuel amounts were almost exclusively biodiesel, but in recent years ethanol has had a growing share of the mix.

#### **3.2.5.5 Uncertainties and time series consistency**

The uncertainty in the activity data and the CO<sub>2</sub> emissions from road transportation is found to be  $\pm 5\%$  and  $\pm 3\%$  of the mean, respectively. In the case of CH<sub>4</sub> and N<sub>2</sub>O, the uncertainty in the emission factors lies on  $\pm 45$  and  $\pm 65$ , respectively (Gustafsson 2005). A detailed description of the uncertainty analysis is given in Annex II.

The total consumption of petrol and auto diesel, and hence the CO<sub>2</sub> emissions from these fuels, are well known. The uncertainty for petrol and auto diesel is related to allocation to non-road use.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category. The data quality is generally better for the latter part of the time series.

#### **3.2.5.6 Category-specific QA/QC and verification**

The comparison of bottom-up estimates of fuel consumption from HBEFA with total sales (category-specific QA/QC) reveals a discrepancy of 3-13 per cent for petrol and 0-18 per cent for diesel. This is deemed to be a reasonable difference. This discrepancy is handled differently for different emission components. The total consumption of each type of fuel is the most important parameter in relation to the reporting requirements of the UNFCCC, as this forms the basis for the calculation of CO<sub>2</sub> from road traffic. One kilogram of gasoline or auto diesel yields a fixed amount of CO<sub>2</sub> irrespective of vehicle type.

The methodology used for calculating N<sub>2</sub>O and CH<sub>4</sub> emissions from road transport has been discussed in previous reviews. Emissions are calculated based on vehicle kilometres driven and not by fuel consumption. Calculations of CH<sub>4</sub>, N<sub>2</sub>O and many other components reported to CLRTAP (e.g., NO<sub>x</sub> and particulates), depends on more detailed information about vehicle types and driving patterns, and thus, a more detailed model (for example HBEFA) should be applied. The relationship between emissions and fuel consumption must be considered differently for the emission components that depends directly on the composition and quantity of fuel (CO<sub>2</sub>, SO<sub>2</sub> and heavy metals) and those who, to a larger

extent, depend on the type of vehicle and driving mode (e.g., NO<sub>x</sub>, CH<sub>4</sub>, N<sub>2</sub>O, NH<sub>3</sub>, CO, particles).

Fuel consumption is not an input to HBEFA, where emissions are calculated based on mileage and number of vehicles in each sub-segment of vehicle classes, as well as other data sets, such as cold start and age distribution of mileage. Fuel consumption is however calculated in the model similarly to emission calculations. Biofuels are not handled as separate fuels in HBEFA. The estimated fuel consumption for the country as a whole can be compared with fuel sales from statistics on deliveries of petroleum products and the energy balance. The petrol consumption in HBEFA is lower than in the energy balance, but the discrepancy is lower the last half of the time series. The difference in diesel consumption is fluctuating in the time series. From 2010 onwards the consumption in HBEFA is lower than in the energy balance and the discrepancy is higher.

It is not known why there is a discrepancy between the consumption of energy balance and bottom-up calculations in HBEFA, but there are several possible explanations as to why fuel sold does not match the fuel consumption calculated from road transport emission model:

- *Fuel purchased by foreign vehicles:* Foreign vehicles is not included in the vehicle register statistics, even though they drive on Norwegian roads. Similarly, no fuel bought by Norwegian vehicles abroad is sampled. It is likely that there is some "fuel tourism" across the Norwegian border, as the diesel price in Norway is lower than in Sweden. The amount is unknown. The current calculations are based on the assumption that driving in Norway by foreign vehicles equals the driving of Norwegian vehicles abroad.
- *Driving patterns:* There may be elements in the driving patterns that cause fuel consumption per kilometre per vehicle to be higher than what the model calculates. One possible reason here is that the fuel consumptions stated in the vehicle type approvals are used as part of the input to the model, and there is an ongoing discussion about whether these systematically underestimates consumption. These data are however available only for the latter part of the series and cannot explain the discrepancies in the 1990s.
- *Non-road use:* The allocation of fuels to non-road use is associated with some uncertainty.

Whether the emission calculations should be corrected for differences in fuel consumption depends on the pollutants in question. For those components that are directly dependent on the amount of fuel (CO<sub>2</sub>, SO<sub>2</sub>, heavy metals), it will always be appropriate to use the fuel consumption from the energy balance as a basis for calculation. For the other emission components, the decision on whether to correct for total fuel consumption or not will

depend on what is causing the discrepancy between fuel consumption calculated in the model and fuel consumption in the energy balance. If the reason is that the total mileage is underestimated in the model, and that the energy balance represents a "truer" picture of the consumption of fuels, emissions should be corrected. If the discrepancy, however, is due to an underestimation of the fuel consumption per kilometre, the emission estimates should not be corrected unless one finds a clear correlation between changes in consumption per kilometre and emissions per kilometre for the relevant emission components. As long as the reason for the discrepancy stays unknown, an assessment of data quality in the various input data is crucial to determining whether emissions should be reconciled against fuel sales or not.

In the previous road transport emission model (SFT 1993; SFT 1999d), the emissions of all substances were corrected to account for the discrepancy between the energy balance and the model calculations, because the energy balance was considered the most secure data source. When HBEFA was introduced as the computational model, a new data source was also introduced, namely the mileage statistics at Statistics Norway. These statistics are based on data from periodical technical inspections and goes back to 2005. This important new data source is considered to be of good quality, and it has changed the assessment of whether the emissions shall be corrected for the consumption of energy balance or not. There is no reason to believe that the total driving lengths are underestimated, and we consider it likely that the reason for the discrepancy lies in the estimates of fuel consumption per kilometre. We have not found any reason to believe that the reasons for the discrepancies in fuel consumption are directly correlated with driving behaviour. It has therefore been assessed that HBEFA estimates of pollutants that are not directly related to fuel consumption should not be reconciled with fuel consumption.

There are currently no comprehensive statistics on foreign vehicles driving in Norway. One possible explanation for the discrepancy between the calculated fuel consumption in HBEFA and sold quantity of fuel is that foreign driving in Norway exceeds driving of Norwegian vehicles abroad. There has been an issue that the proportion of foreign vehicles among heavy goods vehicles increases. However, we see no clear increasing trend in the difference between the model results and sales. Better data related to foreign driving in Norway and the Norwegian driving abroad would strengthen or refute the current assumption that these two balance each other out.



### **3.2.5.7 Category-specific recalculations**

The activity data and emission factors were revised in the time series 1990-2020 due to the new version, HBEFA 4.2 (INFRAS 2022), and national data updates in the model (load and transformation pattern on HGV, and traffic situations). This resulted in reallocation of activity data on the vehicle segments and affect all emissions.

### **3.2.5.8 Category-specific planned improvements**

An assessment of the emission factors is planned for gaseous fuels (N<sub>2</sub>O and CH<sub>4</sub>).

## **3.2.6 Transport – Railways, 1A3c**

### **3.2.6.1 Description**

Railway traffic in Norway uses mainly electricity. Diesel is used at a small number of lines, for shunting etc. There is also a minor consumption of coal in museum railways. In 2021, GHG emissions from this source category accounted for 0.4 % of the total emissions from transport. Emissions from railways decreased by 56 % from 1990 to 2021.

### **3.2.6.2 Methodological issues**

The general estimation methodology for calculating combustion emissions from consumption figures and emission factors is used in this source category.

### **3.2.6.3 Activity data**

Consumption of tax-free diesel used in rail transport is based on invoice information from the sales statistics for petroleum products. From 1990-1994 an allocation key is used to estimate diesel consumption based on total sales deducted consumption in small boats (leisure). Consumption of coal is estimated based on information from different museum railways; the same figure is used for all years from 1990.

### **3.2.6.4 Emission factors**

The emission factors used in this source category are displayed in [Table 3.4](#) for CO<sub>2</sub> and [Table 3.21](#) for CH<sub>4</sub> and N<sub>2</sub>O.

General emission factors for coal are used in the calculations.

### **3.2.6.5 Uncertainties and time series consistency**

The consumption data are considered to be of high quality. Their uncertainty is estimated to be ±5% of the mean. The uncertainty in the emission factors for CO<sub>2</sub> is ±3% of the mean, whereas for CH<sub>4</sub> and N<sub>2</sub>O, the uncertainty is below and above the mean by a factor of 2 and 3, respectively.

A general assessment of time series consistency has not revealed any inconsistencies in

the emission estimates for this category.

#### **3.2.6.6 Category-specific QA/QC and verification**

There is no category-specific QA/QC procedure for this sector. See Annex V for the description of the general QA/QC procedure.

#### **3.2.6.7 Category-specific recalculations**

Revised activity data in the energy balance in the time series 2010-2020 resulted in changes in emissions.

#### **3.2.6.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **3.2.7 Transport – Navigation, 1A3d (Key category for CO<sub>2</sub> and CH<sub>4</sub>)**

#### **3.2.7.1 Description**

According to UNFCCC, Norwegian national sea traffic is defined as ships moving between two Norwegian ports. In this connection, installations at the Norwegian part of the continental shelf are defined as ports. Emissions from fishing are described in section 3.2.10.

Greenhouse gas emissions from navigation constituted 6% of the national GHG total in 2021 and 22% of emissions from transport. Emissions from shipping have increased by 64 % from 1990 to 2021. The increased emissions in the 90s can, to a large extent, be explained by the growing activity in the oil and gas sector in general but especially by the fast-growing production of crude oil and hence the increasing demand for ships transporting the oil from the oil fields to land. Due to the decreasing production of crude oil since 2001, the demand for transport of crude oil has been reduced. Nevertheless, this reduction has been counteracted by growth in demand in other segments of transport.

Navigation is a key category with respect to CO<sub>2</sub> and CH<sub>4</sub> emissions in level both in 1990 and in 2021, and in trend.

#### **3.2.7.2 Methodological issues**

Emissions from navigation are estimated according to the Tier 2 IPCC methodology. Emissions from moveable installations used in oil and gas exploration and extraction are split between energy industries (CRF 1A1) described in section 3.2.2 and navigation: Emissions from drilling and other activities at production and exploration fields are reported under energy industries, while emissions from transport and other activities are

reported under navigation. Emissions from international marine bunkers are excluded from the national totals and are reported separately (see section 3.7.1.2), in accordance with the IPCC guidelines (IPCC 2006).

Annual emissions are estimated from sales of fuel in domestic shipping, using average emission factors in the calculations.

### **3.2.7.3 Activity data**

The annual sales statistics for petroleum products give figures on the use of marine gas oil, heavy distillates and heavy fuel oil in domestic navigation. Information on fuel used in the ship categories in the bottom-up analysis is mainly given by data from the Business Sector's NO<sub>x</sub>-fund for 2007 and by earlier Statistics Norway analyses for 1993 and 1998 (Tornsjø 2001), and 2004.

Fuel sales to the oil and gas extraction sector includes stationary and mobile consumption at offshore facilities as well as consumption at supply ships and other supporting vessels. These sales are split between navigation and energy industries. Information on use for drilling, stationary combustion etc., is reported from the oil companies into the reporting tool Footprint. Consumption for these activities is reported under Energy industries (CRF 1A1c-ii). Only the remaining part of sales, assumed to be for drilling rigs during transit, supply ships, etc., is included with Navigation.

For marine gas oil, the amount used for navigation is equal to total sales figures except bunkers, after the deduction of estimated stationary use, mainly in oil and gas extraction, but also some minor use in manufacturing industries and construction.

Use of natural gas in navigation, which was introduced in 2003 and has increased considerably from 2007, is based on sales figures reported to Statistics Norway from the distributors.

### **3.2.7.4 Emission factors**

#### CO<sub>2</sub>

For CO<sub>2</sub> the following standard emission factors based on carbon content are used:

- Marine gas oil/diesel and special distillate: 73.55 tonne per TJ
- Heavy fuel oil: 78.82 tonne per TJ

CH<sub>4</sub> and N<sub>2</sub>O

For liquid fuels, the general/standard emission factors for CH<sub>4</sub> and N<sub>2</sub>O used in the emission inventory are taken from IPCC/OECD: 0.23 kg CH<sub>4</sub>/tonne fuel and 0.08 kg N<sub>2</sub>O/tonne fuel.

In the case of oil drilling, the employed factors are as follows:

- CH<sub>4</sub>: 0.8 kg/tonne marine gas oil/diesel; 1.9 kg/tonne heavy fuel oil
- N<sub>2</sub>O: 0.02 kg/tonne marine gas oil/diesel.

Some natural gas is combusted as LNG on board vessels; the CH<sub>4</sub> emission factors used are based on the emission factors in [Table 3.19](#). From the year 2000, when the first vessel that used LNG as fuel started operating, a mean factor for all ships weighted after consumption data for the different ship categories (vessels and military ships) are calculated.

| <b>Table 3.19 Methane emission factors for vessels using LNG as fuel gas.</b> |                                                            |                                                      |
|-------------------------------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------|
| <b>Vessel category</b>                                                        | Methane emission factor<br>(kg CH <sub>4</sub> /tonne LNG) | Methane emission factor<br>(kg CH <sub>4</sub> / TJ) |
| <b>Ferry<br/>(Currently lean burn engines only)</b>                           | 44                                                         | 917                                                  |
| <b>Offshore supply<br/>(Currently dual fuel engines only)</b>                 | 80                                                         | 1668                                                 |

Source: MARINTEK (2010), and estimations from Statistics Norway

| <b>Table 3.20 Methane emission factors for vessels using LNG as fuel gas.</b> |                                       |                                |
|-------------------------------------------------------------------------------|---------------------------------------|--------------------------------|
| <b>Year</b>                                                                   | <b>Methane emission factor</b>        | <b>Methane emission factor</b> |
|                                                                               | <b>(kg CH<sub>4</sub> /tonne LNG)</b> | <b>(kg CH<sub>4</sub>/ TJ)</b> |
| <b>1990-2002</b>                                                              | 44                                    | 917                            |
| <b>2003</b>                                                                   | 70.3                                  | 1464                           |
| <b>2004</b>                                                                   | 74.0                                  | 1541                           |
| <b>2005</b>                                                                   | 74.2                                  | 1546                           |
| <b>2006</b>                                                                   | 74.0                                  | 1543                           |
| <b>2007</b>                                                                   | 50.1                                  | 1043                           |
| <b>2008</b>                                                                   | 52.8                                  | 1101                           |
| <b>2009</b>                                                                   | 56.6                                  | 1180                           |
| <b>2010</b>                                                                   | 58.1                                  | 1211                           |
| <b>2011</b>                                                                   | 55.3                                  | 1153                           |
| <b>2012</b>                                                                   | 49.9                                  | 1040                           |
| <b>2013</b>                                                                   | 47.0                                  | 980                            |
| <b>2014</b>                                                                   | 44.7                                  | 931                            |
| <b>2015 -</b>                                                                 | 44.2                                  | 921                            |

Source: MARINTEK (2010), and estimations from Statistics Norway

The IPCC factor for N<sub>2</sub>O from liquid fuels is also used for LNG.

### **3.2.7.5 Uncertainties and time series consistency**

An important source of uncertainty is assumed to be estimation of fuel used by fishing vessels. There is also an uncertainty connected to the fuel use for other domestic sea traffic due to uncertainty in the sale statistics for petroleum products. Important sources of uncertainty are also delimitation of national sea traffic and the emission factors.

The uncertainty in the activity data for navigation is assessed to be  $\pm 20\%$ . With regard to emission factors the uncertainty for ships and fishing vessels is  $\pm 3\%$  of the mean for CO<sub>2</sub>. For CH<sub>4</sub> and N<sub>2</sub>O the corresponding uncertainties lie in the ranges -50 to +100 and -66 to +200 (see also Annex II).

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

### **3.2.7.6 Category-specific QA/QC and verification**

For 1993 and 1998, (Tornsjø 2001), 2004 and 2007, emissions have also been estimated based on a bottom-up. Fuel consumption data were collected for all categories of ships

(based on the full population of Norwegian ships in domestic transport); freight vessels (bulk and tank by size), oil loading vessels, supply/standby ships, tugboats, passenger vessels, fishing vessels, military ships and other ships. Emissions were estimated from ship and size specific emission factors and fuel use. From this information, average emission factors were estimated for application in the annual update based on fuel sales. These results have been compared with top-down data (from sales) on fuel consumption used in the annual estimates. The outcome showed that data from sales were only 1% higher than data from reported consumption in 2007. For 2004, the data sales were 27% higher than the consumption data in the bottom-up analysis. This can be explained by the fact that the bottom-up method does not cover all ships, but it may also be that the domestic/international distinction is not specified precisely enough in the sales statistics. Another element, which has not been taken into account, is possible changes in stock. For the years 1993 and 1998, a deviation of -12 and -15% respectively has been found. In the calculations, sales figures are used, as they are assumed to be more complete and are annually available. The bottom-up approach is unfortunately too resource demanding to conduct annually.

### **3.2.7.7 Category-specific recalculations**

#### **1A3d Domestic navigation/1A4ciii Fishing**

- Revised activity data from the energy balance in the years 2010-2014. Reallocation of emissions from domestic navigation to fishing and international bunkers.

#### **1A3d Domestic navigation/1A5b Military**

- Reallocation of emissions from Ing used in military vessels that was wrongly placed under Domestic navigation in the previous submissions.

### **3.2.7.8 Category-specific planned improvements**

The Norwegian Coastal Administration started in 2011 a project with the aim to use the Automatic Identification System (AIS) to estimate the supply of pollutants from ships to sea. The Norwegian Environment Agency was co-financing the project. In 2015, the delimitation of activities was improved to correspond better to definitions in the inventory. A project in collaboration with Statistics Norway and the Norwegian Coastal Administration is currently looking into how these analyses can be used to improve or verify the inventory for navigation.

## **3.2.8 Transport – Other transportation, 1A3e**

### **3.2.8.1 Description**

In old submissions, this source category included emissions from motorized equipment. Since the previous submission, emissions have been reported under the accurate sectors according to the guidelines (IPCC 2006) i.e., CRF 1A2, 1A4 and 1A5.

### 3.2.8.2 Pipelines

Figures on natural gas used in turbines for pipeline transport at two separate facilities are reported annually from the Norwegian Petroleum Directorate to Statistics Norway. However, energy generation for pipeline transport also takes place at the production facilities. Specific data on consumption for transport are not available. Thus, the consumption at the two pipeline facilities does not give a correct picture of the activity in this sector. For the integrated facilities, the total CO<sub>2</sub> emissions from each facility are reported under the ETS system and are of high quality. The emissions might be split into production and transport using surrogate data, but the accuracy for the two fractions would be much lower than for the total. Consequently, all emissions from pipelines have been reported under 1A1 Energy Industries.

## 3.2.9 Motorized equipment (incl. in 1A2, 1A4 and 1A5)

### 3.2.9.1 Description

The category *motorized equipment* comprises all mobile combustion sources except road, sea, air, and railway transport. Equipment used in agricultural and construction sector is the most important categories. Other categories include mines and quarries, forestry, snow scooters, small boats, and miscellaneous household equipment.

Emissions from motorized equipment are estimated using a common methodology but are reported under several source categories:

- Manufacturing and construction: IPPC 1A2g-vii
- Commercial and institutional: IPPC 1A4a-ii
- Households: IPPC 1A4b-ii
- Agriculture/Forestry/Fishing: IPCC 1A4c-ii
- Military: IPCC 1A5b

Primarily consumption of gasoline and auto diesel is considered.

### 3.2.9.2 Methodological issues

Emissions are estimated through the general methodology described in section 3.2.1, involving consumption figures and appropriate emission factors.

### 3.2.9.3 Activity data

Gasoline and diesel are handled differently. They are both based on data from the energy balance. Diesel used in off-road vehicles are tax-free from 1994, and tax-free diesel in the years 1990-1993 are extrapolated based on the split between diesel with or without tax in 1995-1998.

### Small boats (leisure)

The consumption of gasoline and tax-free diesel is estimated based on a model using data on size of the fleet, type of fuel, 2- and 4-stroke engine, size of engine, and the expenses on fuel. The data is collected from a boating survey (Båtlivsundersøkelsen) in 2011 and 2017, and the time series are extrapolated. The consumption has been assigned to households.

Other motorized equipment on tax-free diesel is given as the difference between total sales of tax-free diesel and estimated use in railway transportation and small boats (leisure).

### Snow scooters

The gasoline consumption is based on the number of scooters, annual mileage, and consumption in litres per kilometres divided on 2- and 4-stroke engines. The fleet data is obtained annually from the Norwegian Public Roads Administration. Annual mileage is assumed to be 850 km/year per scooter. The consumption (l/km) on 2- and 4-stroke engines are based on data from importers of snow scooters. The petrol consumption has been assigned to households.

Other motorized equipment on gasoline (e.g., chainsaws and lawn mowers): 2% of the gasoline consumption (including bioethanol, excluding consumption for leisure boats) in households is assigned to other motorized equipment. The consumption of gasoline in forestry is assigned to other motorized equipment.

### **3.2.9.4 Emission factors**

The emission factors used are presented in [Table 3.4](#) for CO<sub>2</sub>, and [Table 3.21](#) and [Table 3.22](#) for CH<sub>4</sub> and N<sub>2</sub>O.

Emission factors for tractors have been used for tax-free diesel consumption in agriculture and forestry, while emission factors for construction machinery have been used for tax-free diesel consumption in all other industries. The emission factors are calculated from the basic factors in Winther and Nielsen (2006), weighted by the age and engine rating distribution of the tractor and construction machinery populations, as well as assumptions on motor load and operating hours and the introduction scheme for emission regulations by the EU (Stage I, II, III and IV).

Emission factors for snow scooters are adapted from the factors for mopeds in the road traffic emission model.



| Table 3.21 General emission factors for other mobile sources. |                |                       |                        |
|---------------------------------------------------------------|----------------|-----------------------|------------------------|
| Source                                                        | Fuel           | CH <sub>4</sub> kg/TJ | N <sub>2</sub> O kg/TJ |
| Railway                                                       | Auto diesel    | 4.18                  | 27.84                  |
|                                                               | Coal           | 9.96                  | 1.42                   |
| Small boats 2 stroke                                          | Motor gasoline | 116.17                | 0.46                   |
| Small boats 4 stroke                                          | Motor gasoline | 38.72                 | 1.82                   |
|                                                               | Auto diesel    | 4.18                  | 0.70                   |
| Motorized equipment 4 stroke                                  | Motor gasoline | <b>50.11</b>          | 1.59                   |
| Motorized equipment 4 stroke                                  | Auto diesel    | 3.94                  | <b>3.22</b>            |

Source: Bang (1993); SFT (1999d); Statistics Norway (2014a)

Snow scooters have the same emission factors as those for Mopeds, see Table 3.17 and Table 3.18

Bold figures have exceptions for some sectors, see Table 3.22

| Table 3.22 Exceptions from the general factors for greenhouse gases and precursors for other mobile sources. |                         |                |                              |                          |
|--------------------------------------------------------------------------------------------------------------|-------------------------|----------------|------------------------------|--------------------------|
| Component                                                                                                    | Emission factor (kg/TJ) | Fuel           | Source                       | Sectors                  |
| CH <sub>4</sub>                                                                                              | 125.28                  | Motor gasoline | Motorized equipment 4 stroke | Private households       |
| N <sub>2</sub> O                                                                                             | 3.05                    | Auto diesel    | Motorized equipment 4 stroke | Agriculture and forestry |

Source: Bang (1993); SFT (1999d); Statistics Norway (2014a)

### 3.2.9.5 Uncertainties and time series consistency

The estimates of consumption are considered quite uncertain. However, the total consumption of gasoline and auto diesel is well known (see also Annex II).

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

### 3.2.9.6 Category-specific QA/QC and verification

There is no category-specific QA/QC procedure for this sector. For a description of the general QA/QC procedure (see Section 1.2.3).

### 3.2.9.7 Category-specific recalculations

1A2gvii Off-road vehicles and other machinery – Manufacturing and construction

- The activity data in the energy balance was revised from 2010-2020 due to revised activity data on 1A3c railways.
- Some liquid fuels from 2007-2013 were relocated to 1A1ci Manufacture of solid fuels.

*1A4a<sup>iii</sup> Off-road vehicles and other machinery - Commercial/Institutional*

- The activity data in the energy balance was revised from 2010-2020 due to revised activity data on 1A3c railways.

*1A4b<sup>ii</sup> Off-road vehicles and other machinery - Households*

- Recalculated emissions in 2020 due to revised activity data on snow scooters.
- Recalculated emissions from 1990-2020 caused by changes in emission factors for snow scooters. Scooters have the same emission factors as mopeds in road transportation and are affected by these new factors (CH<sub>4</sub> and N<sub>2</sub>O).

**3.2.9.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

**3.2.10 Other Sectors, 1A4 (Key category for CO<sub>2</sub> and CH<sub>4</sub>)****3.2.10.1 Description**

The source category *Other Sectors* includes stationary combustion in agriculture, forestry, fishing, commercial and institutional industries and households, motorized equipment in agriculture and forestry, snow scooters, fishing vessels and pleasure crafts.

In 2020, the emissions from this sector amounted to about 3.1 million tonnes CO<sub>2</sub>-equivalents, which is 6 per cent of national total GHG. The sector emissions decreased by 29 per cent from 1990 to 2021. Throughout the inventory period, emissions have fluctuated although with a decreasing trend. The decreasing trend is mainly due to reduced consumption of fuel oil in the commercial, institutional and households' sectors.

According to the approach 2 key category analysis for 1990 and 2020, this sector is, in conjunction with sectors stationary combustion in 1A1 and 1A2, a key category with respect to:

- Emissions of CO<sub>2</sub> from the combustion of liquid fuels, gaseous fuels, and other fuels in level in 1990 and 2021, and in trend
- Emissions of CO<sub>2</sub> from the combustion of solid fuels in level in 1990 and 2021
- Emissions of CH<sub>4</sub> from the combustion of biomass and gaseous fuels in level in 1990 and 2021 and in trend

This sector is also an Approach 2 key category with respect to CO<sub>2</sub> emissions in mobile fuel combustion in level in 1990 and 2021 and in trend.

### 3.2.10.2 Activity data

#### Motorized equipment

Activity data are as described in section 3.2.9.

#### Households

For the years before 2005 and for 2012, the use of wood in households is based on the annual survey on consumer expenditure which gives the amount of wood burnt. The statistics cover purchase in physical units and estimates for self-harvest of wood. The survey figures refer to quantities acquired, which do not necessarily correspond to use. The survey gathers monthly data that cover the preceding twelve months; the figure used in the emission calculations (taken from the energy balance), is the average of the survey figures from the year in question and the following year. Use of fuelwood in households for the years from 2005 to 2011 and after 2013 is based on responses to questions relating to wood-burning in Statistics Norway's Travel and Holiday Survey. The figures in the survey refer to quantities of wood *used*. The survey quarterly gathers data that cover the preceding twelve months. For the period 2005 to 2011 the figure used in the emission calculations is the average of 5 quarterly surveys (1 survey per quarter plus a round of bonus questions in the 4<sup>th</sup> quarter). Since 2013 the figure used in the emission calculations is the average of 3 quarterly surveys (Quarters 1, 2, and 4). Household biomass combustion is minimal in the 3<sup>rd</sup> quarter, and therefore has little overall effect on results. Otherwise, the surveys used in 2005-2011 and after 2013 are identical. All surveys used to gather data on household wood combustion have used the same methodology for sampling and controlling for bias in sampling and missing responses, reducing the risk for inconsistency in the time series. Combustion takes place in small ovens in private households. The general downward trend in emissions since 2012 can be attributed to reduced consumption of wood due to increased electrification of household heating, milder winters, and the phasing in of more efficient wood stoves using newer technology.

Figures on use of coal and coal coke are derived from information from the main importer. Formerly, Norway's only coal producing company had figures on coal sold for residential heating in Norway. From about 2000, this sale has been replaced by imports from abroad. The volumes of imported charcoal for grocery trade, garden centres, retail sale of furniture and other shops that sell items for the home are placed under household consumption.

For the period 2002-2005 the LPG consumption in households is estimated by distributors.

From 2005 and onwards, total consumption is given by the annual sales statistics for petroleum products and distributed using the shares of direct sales in 2009-2012, as for agriculture. The consumption is split in use for transport (in passenger cars) and stationary use by estimates from distributors. The estimated use in transport is currently constant for

a larger part of the time series, as new estimates have not been attained for a number of years. Consumption of light heating oil and heating kerosene in households is calculated using consumption figures collected as part of Statistics Norway's survey of consumer expenditure (FBU) (Norway 2013). This survey was conducted for the years 1993, 1994, 1995, 2001, 2004, 2006, 2009 and 2012, and households were asked to report the volumes of oil and kerosene they had procured during the past 12 months. The intervening years are calculated using changes in sales of light heating oil and heating oil from the statistics on sales of petroleum products, adjusted for consumption in manufacturing and mining (Norway 2018; Statistics Norway Annually-b). This is because consumption in manufacturing and mining is less dependent on temperatures than household consumption. Use of natural gas has been based on sales figures reported to Statistics Norway from the distributors. Statistics Norway has a separate model for calculating fuel used in leisure boats by households. Activity data is described in section 3.2.9.

### Agriculture

The figures for consumption of off-road diesel in agriculture come from Statistics Norway's Sample Survey of Agriculture and Forestry (LU). This is a form-based sample survey where agricultural holdings report how much diesel they have used in their business activity. Questions regarding energy are only included in LU every 3–4 years. Activity data for intervening years is calculated by using the percentage change in quantities in the aggregate accounts for diesel of the Budget Committee for Agriculture as calculated by the Budget Committee for Agriculture (Nibio).

Figures on LPG consumption prior to 2005 are taken from agriculture statistics. From 2005 and onwards, total consumption is given by the annual sales statistics for petroleum products and distributed to agriculture industry using the share of direct sales in 2009–2012. Until further work is done, the same distribution formula is applied to all these years. A figure on the minor use of coal was previously collected annually from the only consumer. Since 2002, however, there has been no use of coal in the Norwegian agricultural activities. Use of natural gas in agriculture, which has increased considerably since it first was registered in 2003, is based on sales figures reported to Statistics Norway from the distributors. The survey was first carried out in 2004, but data on inland consumption of natural gas had been collected since 1994. Prior to 1994 the consumption was insignificant.

Consumption of petroleum products that is not mentioned above (heating kerosene, light heating oil and heavy gas oil) is covered by the annual statistics on sales of petroleum products. Distributor sales are broken down by industry according to distribution formulas.

### Fishing

Consumption of petroleum products (off-road diesel, heating kerosene, light heating oil, marine gas oil, heavy gas oil and LPG) is covered by the annual statistics on sales of petroleum products. Distributor sales are broken down by industry according to distribution formulas. Monetary figures on refunds of and exemptions from the basic fee on mineral oil are used for distributing consumption of marine gas oil that is not sold directly to industries. Only industries where substantial amounts of marine gas oil are consumed are included: Fishing, extraction of crude petroleum and natural gas, domestic coastal transport, and international sea transport. It is assumed that the distribution of refunds and exemptions from the fee is representative for the distribution of consumption of marine gas oil, even though all mineral oils are covered by the fee. The figures are not consistent and do not cover all the relevant industries until 2015. Thus, the figures for 2015 are used for the years 2010-2015.

### Commercial and institutional sectors

Consumption of petroleum products is retrieved from the statistics on sales of petroleum products. For stationary petroleum products like light heating oil and heating kerosene, more sales are made directly to users than via distributors. The distribution of the direct sales will then be used as distribution formulas, with the assumption that the direct sales have the same industrial classification as the distributor sales.

From 2005 and onwards, total consumption of LPG is given by the annual sales statistics for petroleum products and distributed using the shares of direct sales in 2009-2012, as for agriculture. It is assumed that LPG consumption in the transport industries, as well as sale and maintenance of vehicles, support activities for transportation and rental and leasing activities is used for transport. For the years prior to 2005 the source of LPG consumption is statistics on the construction industry.

Consumption of natural gas is collected in a separate survey. When necessary, assumptions are made to break down consumption in accordance with the detailed industrial classification. Calculated emissions from combustion of biogas at a sewage treatment plant are included for all years since 1993.

#### **3.2.10.3 Emission factor**

The emission factors used in this source category are presented in sections 3.2.1 and 3.2.9. For residential wood burning three separate emission factors are used, corresponding to wood-burning method: wood burning stoves that use older technology (before 1998) emit

16.11 g/kg (959 kg/TJ), wood burning stoves that use newer technology (after 1998) emit 3.88 g/kg (228 kg/TJ), and open fireplaces emit 5.3 g/kg (315 kg/TJ). These emission factors are based on findings by Seljeskog et al (2017), where wood stoves using newer technology have greatly reduced methane emissions per unit of biomass burned. The emission factor for newer stoves is used increasingly as time goes on due to older stoves being phased out in Norwegian households.

#### **3.2.10.4 Uncertainties**

Uncertainty in fishing is described together with navigation in section 3.2.7.

Uncertainty is reduced for sectors where use was previously given as a residual, e.g., use of heating kerosene and heavy distillates in households, and total use of fuel oil in commercial and institutional industries. Generally, the uncertainty, applies mainly to the distribution of use between industries – the total use is defined as equal to registered sales, regardless of changes in stock.

The uncertainty in the activity data for this source category is  $\pm 20\%$  of the mean for solid and liquid fuels, and  $\pm 30\%$  of the mean for biomass and waste (see Annex II).

#### **3.2.10.5 Category-specific QA/QC and verification**

There is no category-specific QA/QC procedure for this sector. For a description of the general QA/QC procedure (see section 1.2.3).

#### **3.2.10.6 Category-specific recalculations**

##### *1A4ai Stationary*

- Revised activity data from the energy balance and correction of double-counting of natural gas consumption in the years 2019-2020, resulting in reduced emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

##### *1A4bi Stationary*

- Revised activity data from the energy balance in the years 2019-2020 and corrections to firewood consumption in 2020, resulting in slightly reduced emissions of CH<sub>4</sub> and N<sub>2</sub>O in 2019 and 2020, and a larger decrease in CO<sub>2</sub> emissions in 2020.

##### *1A4bii Households (mobile)*

- Revised activity data from the energy balance in the years 2019-2020, resulting in slightly reduced emissions of CH<sub>4</sub>.

##### *1A4ci Stationary*

- Revised activity data from the energy balance in the year 2020, resulting in reduced emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

*1A3d Domestic navigation/1A4ciii Fishing*

- Revised activity data from the energy balance in the years 2010-2014. Reallocation of emissions from domestic navigation to fishing and international bunkers.

**3.2.10.7 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

**3.2.11 Other emissions from energy combustion, 1A5 (Key category for CO<sub>2</sub>)**

This source includes emissions from fuel use in military stationary and mobile activities, and the use of lubricants in mobile combustion.

In 2021, the emissions from this sector amounted to about 0.1 million tonnes CO<sub>2</sub>-equivalents, which is 0.2 per cent of national total GHG. The sector emissions decreased by 77 per cent from 1990 to 2021. The trend fluctuates significantly, mainly due to annual changes in military procurement.

**3.2.11.1 Description**Military

Emissions of CO<sub>2</sub> from the other mobile sub-sector (1A5b) is a key category according to approach 1 with respect to CO<sub>2</sub> emissions in level in 1990 and 2021 and in trend.

Emissions from non-fuel use of liquid fuels

In the energy balance, small amounts of gasoline, auto diesel and residual fuel oil is reported as used for non-fuel purposes. A fraction of this consumption is estimated to result in emissions to air, while the remaining fractions remain in products or enter waste streams.

Lubricants in mobile combustion

Two-stroke petrol engines are lubricated by adding oil to the petrol. The oil is thus combusted and converts to CO<sub>2</sub>. As lubricant, oil in two-stroke petrol is not included in the Norwegian energy statistics, a separate estimation must be performed to obtain completeness.

**3.2.11.2 Activity data and Emission factors**Military

Fuel used in the military is annually collected from the sale statistics of petroleum products. From 2010, figures of aviation kerosene are collected from the Norwegian Defense Research Establishment and are used as a supplement in 1A5b Military mobile.

Emission factors used for stationary activities are presented in section 3.2.1 and emission factors used for mobile activities are presented in the corresponding transport sectors (see sections 3.2.4 to 3.2.9). The stationary and mobile emissions from the Norwegian military activities for the years 1990-2021 are presented in [Table 3.23](#).

| <b>Table 3.23 Stationary and mobile emissions from military activities. 1990-2021.</b><br><b>CO<sub>2</sub> in 1000 tonnes, CH<sub>4</sub> and N<sub>2</sub>O in tonnes</b> |                            |                 |                  |                        |                 |                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|-----------------|------------------|------------------------|-----------------|------------------|
|                                                                                                                                                                             | 1A5a Military – stationary |                 |                  | 1A5b Military – mobile |                 |                  |
|                                                                                                                                                                             | CO <sub>2</sub>            | CH <sub>4</sub> | N <sub>2</sub> O | CO <sub>2</sub>        | CH <sub>4</sub> | N <sub>2</sub> O |
| <b>1990</b>                                                                                                                                                                 | 79.81                      | 10.85           | 0.65             | 401.56                 | 13.61           | 11.87            |
| <b>1995</b>                                                                                                                                                                 | 48.06                      | 6.75            | 0.43             | 498.09                 | 18.84           | 14.90            |
| <b>2000</b>                                                                                                                                                                 | 33.90                      | 4.61            | 0.28             | 214.65                 | 12.76           | 6.07             |
| <b>2005</b>                                                                                                                                                                 | 26.56                      | 3.61            | 0.22             | 305.42                 | 9.27            | 9.07             |
| <b>2010</b>                                                                                                                                                                 | 32.72                      | 4.44            | 0.27             | 182.64                 | 6.12            | 5.46             |
| <b>2011</b>                                                                                                                                                                 | 31.09                      | 4.02            | 0.22             | 201.61                 | 8.03            | 6.09             |
| <b>2012</b>                                                                                                                                                                 | 25.32                      | 3.23            | 0.18             | 187.22                 | 6.86            | 5.65             |
| <b>2013</b>                                                                                                                                                                 | 22.74                      | 2.89            | 0.16             | 202.37                 | 7.78            | 5.96             |
| <b>2014</b>                                                                                                                                                                 | 11.07                      | 1.51            | 0.09             | 215.52                 | 8.62            | 6.30             |
| <b>2015</b>                                                                                                                                                                 | 7.72                       | 1.05            | 0.06             | 176.43                 | 6.62            | 5.17             |
| <b>2016</b>                                                                                                                                                                 | 5.79                       | 0.79            | 0.05             | 179.72                 | 6.31            | 5.29             |
| <b>2017</b>                                                                                                                                                                 | 7.91                       | 1.08            | 0.06             | 182.73                 | 6.35            | 5.38             |
| <b>2018</b>                                                                                                                                                                 | 2.58                       | 0.35            | 0.02             | 145.43                 | 4.21            | 4.35             |
| <b>2019</b>                                                                                                                                                                 | 1.86                       | 0.25            | 0.02             | 108.98                 | 1.36            | 3.45             |
| <b>2020</b>                                                                                                                                                                 | 0.06                       | 0.01            | 0.00             | 106.92                 | 1.59            | 3.38             |
| <b>2021</b>                                                                                                                                                                 | NO                         | NO              | NO               | 106.74                 | 1.84            | 3.46             |

Source: Statistics Norway

#### Emissions from non-fuel use of liquid fuels

*Activity data:* Total non-fuel domestic consumption of fuel oils is obtained from the Norwegian energy balance. The quality of the data is mixed throughout the time series. Annual surveys of feedstock use were performed for 1993-2001. For 2002 a different type of survey was used.

In addition to gas/diesel oil, gasoline and residual fuel oil has been recorded earlier in the time series.

Times series for the non-fuel use of these fuels are given in section 3.6.2 on feedstocks etc.

*Fraction emitted:* Gas/diesel oil and gasoline: 0.5, and residual oil: 0.11.



*Emission factors:* General emission factors for liquid fuels were obtained from [Table 3.4](#), [Table 3.6](#) and [Table 3.7](#). The selected factors are 3 kg CH<sub>4</sub>/TJ and 0,6 kg N<sub>2</sub>O/TJ.

#### Lubricants in mobile combustion

The amount of combusted lubricant oil is proportionate to the consumed two-stroke petrol. The blend ratio is assumed to be falling linearly from 3% in 1990 to 2% in 2012, based on Internet search (retailers and discussion fora 2014, pages in Norwegian only). Parts of the two-stroke petrol are blended abroad (petrol retailers pers. comm., 2014), and the estimated CO<sub>2</sub> emission from this lubricant oil is hence included in the emission estimates for petrol. The share being blended abroad is not known and is assumed to be 50%.

The amount of oil giving emissions not already accounted for is estimated by multiplying the two-stroke petrol consumption by the oil blend ratio and the share of petrol being blended in Norway:

$$E = A \times R \times D$$

where:

*E* = emission

*A* = consumed two-stroke petrol

*R* = blend ratio (oil:petrol)

*D* = share of two-stroke petrol being blended domestically

CH<sub>4</sub> and N<sub>2</sub>O

The conversion from tonnes of consumed lubricant to tonnes of emitted CO<sub>2</sub>, is performed based on IPCC default factors for energy content (NCV) and carbon content per unit of energy.

**Table 3.24 Conversion factors used to estimate CO<sub>2</sub> emissions.**

| Factor                    | Value  | Unit       |
|---------------------------|--------|------------|
| Net calorific value (NCV) | 0.0402 | TJ/tonne   |
| Carbon content (CC)       | 20     | Tonne C/TJ |

Source: IPCC (2006)

N<sub>2</sub>O and CH<sub>4</sub> emissions have been estimated as fixed fractions of the CO<sub>2</sub> emission, based on IPCC default factors.

**Table 3.25 Conversion factors used to estimate CH<sub>4</sub> and N<sub>2</sub>O emissions.**

| Factor                | Value   | Unit                                                   |
|-----------------------|---------|--------------------------------------------------------|
| <b>CH<sub>4</sub></b> | 0.00286 | Tonne CO <sub>2</sub> eq/tonne CO <sub>2</sub> emitted |
| <b>N<sub>2</sub>O</b> | 0.00254 | Tonne CO <sub>2</sub> eq/tonne CO <sub>2</sub> emitted |

Source: IPCC (2006)

### 3.2.11.3 Uncertainties

#### Military

There have been large variations in annual sales of military aviation kerosene prior to 2010 as stock changes have not been considered. The actual annual use of kerosene and hence emissions is therefore uncertain prior to 2010.

#### Lubricants in mobile combustion

The uncertainty in the emissions estimate from lubricant use in two-stroke petrol engines is assumed to be moderate. The total consumption of gasoline is well known, while the amount going to two-stroke petrol engines is estimated. The uncertainty in the activity data is assumed to be 20%, based on the uncertainty in the road traffic estimation (see section 3.2.5). The uncertainty of the carbon content is an IPCC default value, and the NCV uncertainty is assumed to be equally large. Based on these uncertainties, the overall uncertainty of the emissions from lubricating oil used in two-stroke petrol engines is estimated to be 30%.

### 3.2.11.4 Category-specific recalculations

#### *1A3d Domestic navigation/1A5b Military*

- Reallocation of emissions from lng used in military vessels that was wrongly placed under Domestic navigation in the previous submissions.

#### *1A5b2 Lubricants – two stroke engines*

- Revised activity data. The amounts of lubricants used in two stroke engines were updated and led to a slight increase in the emissions of CO<sub>2</sub> in the period 2010-2020. Details are given in chapter 10.

### 3.2.11.5 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 3.3 Fugitive Emissions from Coal Mining and Handling, 1B1 (Key category for CH<sub>4</sub>)

#### 3.3.1 Description

Coal has been shipped from Svalbard since 1907. In 2021 one coal mine (mine 7 near Longyearbyen) at Spitsbergen (the largest island in the Svalbard archipelago) operated by a Norwegian company. This mine is producing coal for export and today about 1/4 of the produced coal is used at the power plant in Longyearbyen. The mines at Svea, 60 kilometers south of Longyearbyen, have not been in production since 2017. As the Norwegian GHG inventory, according to official definitions, shall include emissions from all activities at Svalbard, emissions from Russian coal production have also been estimated and included in the Norwegian greenhouse gas inventory. Until 1998, coal was produced in two Russian mines, Barentsburg and Pyramiden, but since then, production takes place only in the Barentsburg mine. The mines near Longyearbyen and at Pyramiden are defined as surface mines, whereas the mine in Barentsburg is an underground mine.

Abandoned underground mines is included in the inventory. In 2005 there was a fire in one of the Norwegian coal mines and consequently the production was almost halved from 2004 to 2005 as Figure 3-12 illustrates. The emissions from this fire are included in the inventory. The CO<sub>2</sub> emissions from the fire are estimated to approximately 3000 tonnes.

Russian production has since 2001 been considerably smaller than the production from Norwegian mines. In 2008 a fire broke out in the Russian mine at Barentsburg. Shortly after the fire started, the mine was filled with water. Hence there were no significant emissions from the fire, and these emissions are not estimated. Russian activity data are more uncertain than the Norwegian, which causes a correspondingly higher uncertainty in the emission figures.

A smouldering fire has taken place in the mine Pyramiden, the Russian mine that was closed in 1998. At an inspection in 2005, no emissions were registered, which indicates that the fire had burnt out. Due to lack of data, emissions for earlier years from this fire have not been estimated. However, Norwegian authorities assume that these emissions were limited.

Emissions from NMVOC and particles from handling of coal are included in the inventory. Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are reported separately in CRF Table 6.

The total emissions from mining, including abandoned mines, is reduced by 57% from about 3 kilotonne in 1990 to 79 kilotonne CO<sub>2</sub> equivalents in 2021. In 2021 abandoned mines represented 67% of total emissions from source category 1.B.1. The emissions from mining, excluding from abandoned mines, were in 2021 estimated to 26 kilotonnes of CO<sub>2</sub> equivalents. The emissions, excluding from abandoned mines, increased by 3% from 2020 to 2021. Total coal production increased by 60% to 0,14 million tonnes, but production in underground mines was flat.

Figure 3-12 shows that the production of coal at Svalbard has decreased by 73% from 1990 to 2021. There was a peak in the production in 2007 when the production was ten times higher than in 1990. The production increased by 80% from 2000 to 2001 due to the start-up of a new Norwegian mine.

CH<sub>4</sub> from coal mining is defined as key category according to Approach 2 in both level and trend.

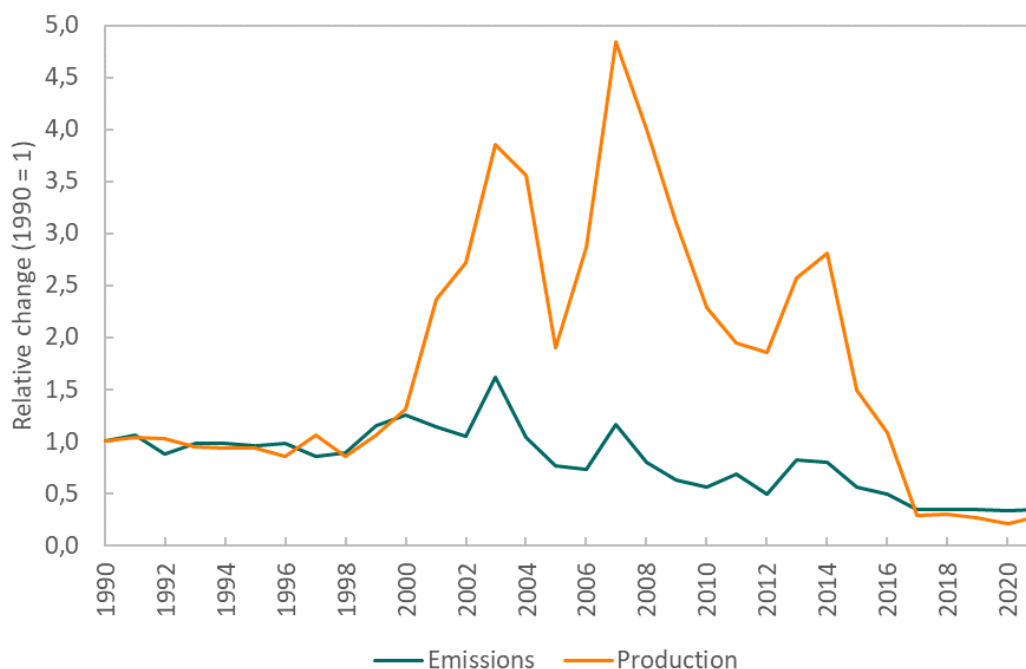


Figure 3-12 Relative change in coal production in Norway and related GHG emissions in the period 1990-2021. Excluding emissions from abandoned underground mines. 1990=1

### 3.3.2 Methodological issues

#### 3.3.2.1 CO<sub>2</sub>

Indirect CO<sub>2</sub> emissions from methane and NMVOC oxidized in the atmosphere are calculated by multiplying the calculated CO<sub>2</sub> and NMVOC emissions with, respectively, the factors 2.75 tonne CO<sub>2</sub> per tonne CO<sub>2</sub> and 2.2 tonne CO<sub>2</sub> per tonne NMVOC. (See Chapter 9 for more information about indirect CO<sub>2</sub>).

#### 3.3.2.2 CH<sub>4</sub>

Emissions of methane from coal mining on Svalbard are calculated by multiplying the amount of coal extracted (raw coal production) with country specific emission factors (Tier 2). The calculations are performed by Statistics Norway.

#### 3.3.2.3 NMVOC

NMVOC emissions from handling of coal are estimated by multiplying the amount of coal extracted (raw coal production) with Tier 2 emission factors from EMEP/EEA Guidebook (2013).

### 3.3.2.4 Abandoned underground mines

Methane emissions from abandoned underground mines have been calculated with a Tier 1 methodology from the 2006 IPCC Guidelines, using the following formula:

$$CH_4 \text{ emissions} = \text{Number of abandoned coal mines remaining unflooded} \\ * \text{Fraction of gassy coal mines} * \text{Emission factor} * \text{Conversion factor}$$

The conversion factor is the density of CO<sub>2</sub> and converts volume of CO<sub>2</sub> to mass of CO<sub>2</sub>. The conversion factor (density) has a value of 0.67 \*10<sup>-6</sup> Gg m<sup>-3</sup>.

### 3.3.3 Activity data

Figures on Norwegian production (raw coal production) are reported by the plant to Statistics Norway. Russian figures are reported to the Norwegian authorities on Svalbard; these figures are, however, regarded as highly uncertain, consisting of a mixture of figures on production and shipments.

The national Energy balance only includes Norwegian production. Thus, the activity data in 1B1a will differ from the coal production data in the Reference Approach.

#### 3.3.3.1 Abandoned underground mines

Information on the history of mining at Svalbard was obtained from the Directorate of Mining with the Commissioner of Mines at Svalbard in 2014. The information from the directorate included assessment of degree of flooding. Where no information about flooding is available, the mines are included in the number of abandoned mines remaining unflooded, to avoid underestimation. Table 3.26 gives an overview of the number of abandoned mines remaining unflooded for different time periods of abandonment, as well as the used fractions of gassy mines for each time period.

**Table 3.26 Number of mines abandoned from 1901-present.**

| Time of abandonment | Number of abandoned mines remaining unflooded | Fraction of gassy mines |
|---------------------|-----------------------------------------------|-------------------------|
| 1901-1925           | 6                                             | 0.5                     |
| 1926-1950           | 3                                             | 0.3                     |
| 1951-1975           | 7                                             | 0.4                     |
| 1976-2000           | 6                                             | 0.3                     |
| 2001-present        | 0                                             | 0.0                     |

*Directorate of Mining (2014)*

It is assumed that all historic coal mining activities in Norway has taken place at Svalbard.

### 3.3.4 Emission factors

#### 3.3.4.1 CO<sub>2</sub>

For Norwegian coal production a country specific emission factor of CO<sub>2</sub> from extraction of coal was determined in 2000 in two separate studies performed by (IMC 2000) and Bergfald & Co AS (2000).

The emissions of methane from coal mining were in the study measured in two steps. First, coal was sampled and the methane content in coal was analysed (IMC 2000). The sampling process started after a long period (a week) of continuous production. Small samples of coal were removed directly from the coalface as soon as possible after a cut was taken. This was to minimize degassing losses in the samples if the face or heading had been standing for a long time.

The samples yielded an estimate of seam gas content of 0.535-1.325 m<sup>3</sup> methane per tonne coal derived from an average content of 0.79 m<sup>3</sup> per tonne. This factor includes the total possible methane emissions from coal mining, loading and transport on shore and on sea. The factor also includes the possible emission from handling and crushing of coal at the coal power plant.

Secondly, the methane content in ventilation air from the underground coal mines at Spitsbergen was measured (Bergfald & Co AS 2000). From the Norwegian mines the methane content in the ventilation air was measured to 0.1-0.4 m<sup>3</sup> methane per tonne coal.

Considering the measurements, it was therefore decided to use 0.54 kg methane per tonne coal as emission factor when calculating methane emissions from coal mining in Norway. According to IPCC`s Good Practice Guidance, the Norwegian mines at Spitsbergen have characteristics that should define the mines as underground mines, whereas the emission factor we use is more characteristic for surface mines. The low content of methane is explained with the mine's location 300-400 meters *above* sea level. Furthermore, the rock at Spitsbergen is porous and therefore methane has been aired through many years.

For the Russian mine in Barentsburg, the emission factor for CO<sub>2</sub> has been estimated in the same manner as the Norwegian factor, based on measurements by Bergfald & Co AS (2000). This is an underground mine, which causes considerably higher emissions than from the Norwegian mines; we use the factor 7.16 kg methane per tonne coal for this mine. Pyramiden, the Russian mine that was closed down in 1998 is, however, situated

more like the Norwegian mines; accordingly, we use the same emission factor for this as for the Norwegian mines.

### 3.3.4.2 NMVOC

Emission factors for NMVOC are taken from EEA (2019). The Tier 2 factors used are 0.2 kg NMVOC per tonne coal for surface mines and 3 kg NMVOC per tonne coal for underground mines.

### 3.3.4.3 Abandoned underground mines

The fraction of gassy mines is determined by the Norwegian Environment Agency based on information about geological characteristics of the different geographic areas of Svalbard, obtained from Bergfald & Co AS (2000) and Directorate Mining with the Commissioner of Mines at Svalbard.

Default emission factors from the tier 1 methodology of the IPCC Guidelines (IPCC 2006) are used (Table 3.27). The complete table may be found as table 4.1.6 in volume 2 of the guidelines. The table has been extrapolated from 2016 to 2020 by Statistics Norway.

**Table 3.27 Emission factors used for calculating emissions from abandoned underground mines. Million m<sup>3</sup> CO<sub>2</sub> /mine.**

| Inventory year | Time period of abandonment |           |           |           |              |
|----------------|----------------------------|-----------|-----------|-----------|--------------|
|                | 1901-1925                  | 1926-1950 | 1951-1975 | 1976-2000 | 2001-present |
| 1990           | 0.281                      | 0.343     | 0.478     | 1.561     | NA           |
| 1995           | 0.272                      | 0.327     | 0.439     | 0.921     | NA           |
| 2000           | 0.264                      | 0.314     | 0.408     | 0.713     | NA           |
| 2005           | 0.256                      | 0.301     | 0.382     | 0.601     | 1.265        |
| 2010           | 0.249                      | 0.29      | 0.361     | 0.529     | 0.845        |
| 2011           | 0.248                      | 0.288     | 0.357     | 0.518     | 0.801        |
| 2012           | 0.247                      | 0.286     | 0.353     | 0.507     | 0.763        |
| 2013           | 0.246                      | 0.284     | 0.35      | 0.496     | 0.73         |
| 2014           | 0.244                      | 0.283     | 0.346     | 0.487     | 0.701        |
| 2015           | 0.243                      | 0.281     | 0.343     | 0.478     | 0.675        |
| 2016           | 0.242                      | 0.279     | 0.34      | 0.469     | 0.652        |
| 2017           | 0.241                      | 0.277     | 0.336     | 0.461     | 0.625        |
| 2018           | 0.239                      | 0.275     | 0.333     | 0.453     | 0.604        |
| 2019           | 0.238                      | 0.273     | 0.33      | 0.446     | 0.586        |
| 2020           | 0.237                      | 0.272     | 0.327     | 0.439     | 0.577        |
| 2021           | 0.236                      | 0.27      | 0.324     | 0.432     | 0.555        |

Source: (IPCC 2019)



### 3.3.5 Uncertainties and time-series consistency

The uncertainty in the activity data concerning Norwegian coal production is regarded as being low. The uncertainty in Russian data is regarded being considerably higher.

Today, country specific factors based on measurements are used in the calculations. We assume that the uncertainty in the EF is much lower than that reported in Rypdal and Zhang (2000), when an IPCC default emission factor was used. In Rypdal and Zhang (2000) the uncertainty in the EF was estimated by expert judgments to as much as -50 to +100%.

The EF we use for the Norwegian mines is an average of the measurement of methane in coal sampled in the study (IMC 2000). This average EF is two to eight times higher than the methane content measured in ventilation air by Bergfald & Co AS (2000). This should indicate that the chosen emission factor is rather conservative.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

For abandoned underground mines the same data source is used for the entire time series, and no time series inconsistencies are identified for the calculation of CO<sub>2</sub> emissions from.

### 3.3.6 Category-specific QA/QC and verification

Independent methods to estimate the EFs used in the calculations are described above in this chapter.

Statistics Norway and the Norwegian Environment Agency carry out internal checks of the emission time-series and corrections are made when errors are detected; see Section 1.2.3 for general QA/QC procedures.

For abandoned underground mines no category-specific QA/QC routines are in place for the emission estimates.

### 3.3.7 Category-specific recalculations

*Reallocation:* Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

Emission factors were updated according to the IPCC 2019 refinements, resulting in some slight changes in CH<sub>4</sub> emissions for the years 2017-2020

### 3.3.8 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 3.4 Fugitive Emissions from Oil and Natural Gas – 1B2

### 3.4.1 Overview

Production of oil and gas on the Norwegian continental shelf started on 15 June 1971 when the Ekofisk field came in production, and in the following years several major discoveries were made. By turn of the year 2022/2023, 93 fields were producing oil and gas. One new field started production in 2022. A further five fields were under development at the end of the year (OED 2023).

The overall trend is that the total production of oil, gas and NGL and condensate has been decreasing since peak production of 264 mill. Sm<sup>3</sup> o.e. in 2004 (Figure 3-13). The increase in production from 1990 to 2004 was 111%.

In 2021, the total production was 86% higher than in 1990, and 2% higher than in 2020. From 2020 to 2021, oil production increased by 4% and gas production by 3%, respectively. Production data also shows that gas production was for the first time higher than the production of oil in 2010, and in 2021 it was about 12% higher than the production of oil. For more information about the Norwegian petroleum sector see OED (2023).

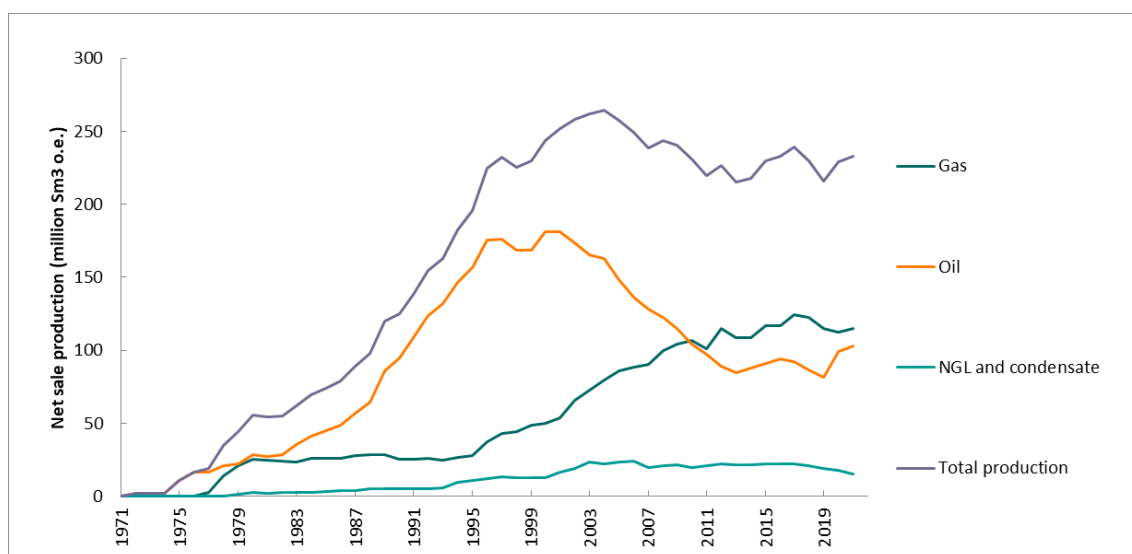


Figure 3-13. Net sale production of oil, gas and NGL and condensate in 1974-2021. Million Sm3 oil equivalents. Source: Norwegian Petroleum Directorate

The sector Fugitive Emissions from Oil and Natural Gas (1B2) includes fugitive emissions mainly connected to oil and gas exploration and production, gas terminals and refineries. Emissions from combustion for energy purposes in the source categories mentioned above are reported in source category 1.A.c. These are emissions from combustion of natural gas and diesel in turbines, motors, and boilers. A description of methodology for reported fugitive emissions is provided below.

As response to the 2009 annual review, sale production of oil, NGL and condensate is reported in the CRF in source category 1.B.2.a.2 "Production oil" and sale production of gas in 1.B.2.b.2 "Production/processing gas".

#### 3.4.1.1 Fugitive emissions 1990-2021

Fugitive emissions from oil, natural gas and venting and flaring, excluding CCS, accounted for 4% of the total GHG emissions in Norway in 2021, and 6% of the total GHG emissions in the energy sector.

Figure 3-14 shows the trend in fugitive emissions from oil and gas production, venting and flaring, and Figure 3-15 shows the relative change in emissions from the same sources. The total sector emissions decreased by 28% from 1990 to 2021, but increased by 8% from 2020 to 2021.

This includes CO<sub>2</sub> emissions from catalyst regeneration (coke burn-off) in a catalytic cracker unit at one refinery. This particular source constitutes close to all emissions reported in CRF category 1.B.2.a.4 and normally about 30-40% of the total emissions reported in 1B2. The low emissions in 2019 and 2020 are mainly caused by lower activity as this catalytic cracker was replaced and therefore out of operation.

The fugitive emissions from oil and gas activities, excluding 1.B.2.a.4, decreased by 44% between 1990-2021, while the total production of oil, gas and NGL and condensate increased by 86%. The different development in emissions and production is mainly explained by measures taken to reduce NMVOC emissions from storage and loading of crude oil offshore and onshore, measures to reduce venting of CO<sub>2</sub> offshore and that flaring of gas is for most years lower than in 1990. It is prohibited to flare at oil and gas fields offshore other than for security reasons. The peak emissions from flaring in 2007-2008 (Figure 3-14) were due to start-up problems at an LNG plant. From 2009 the plant came into more regular production. More information about flaring offshore is given in chapter 3.4.1.2.

Emissions from 1.B.2.a.3 transport, which are mainly indirect CO<sub>2</sub> emissions of NMVOC and CH<sub>4</sub> from storage and loading of crude oil offshore and onshore, are reduced substantially due to implemented measures. The reduction has been partly counteracted by increased emissions from catalytic cracking in 1.B.2.a.4. Emissions from natural gas increased by orders of magnitude between 1990 and 2009 due to increased domestic gas distribution but have been largely constant thereafter. In 2009 the emissions were about 81 kilotonne CO<sub>2</sub> equivalents.

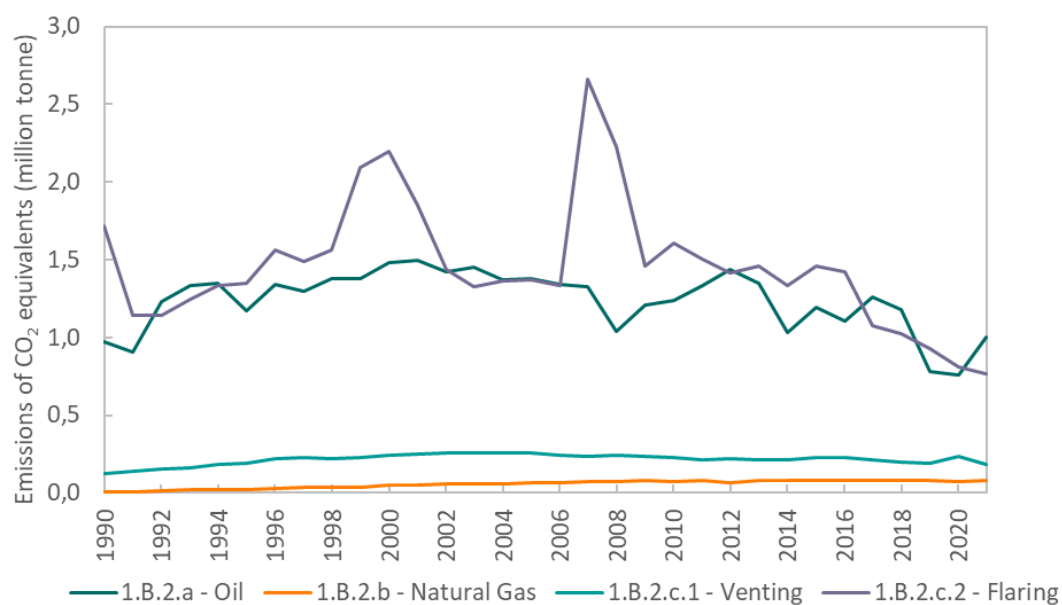


Figure 3-14. 1.B.2 Fugitive emissions from oil and gas related activities. Million tonne CO<sub>2</sub> equivalents. Source: Statistics Norway/Norwegian Environment Agency

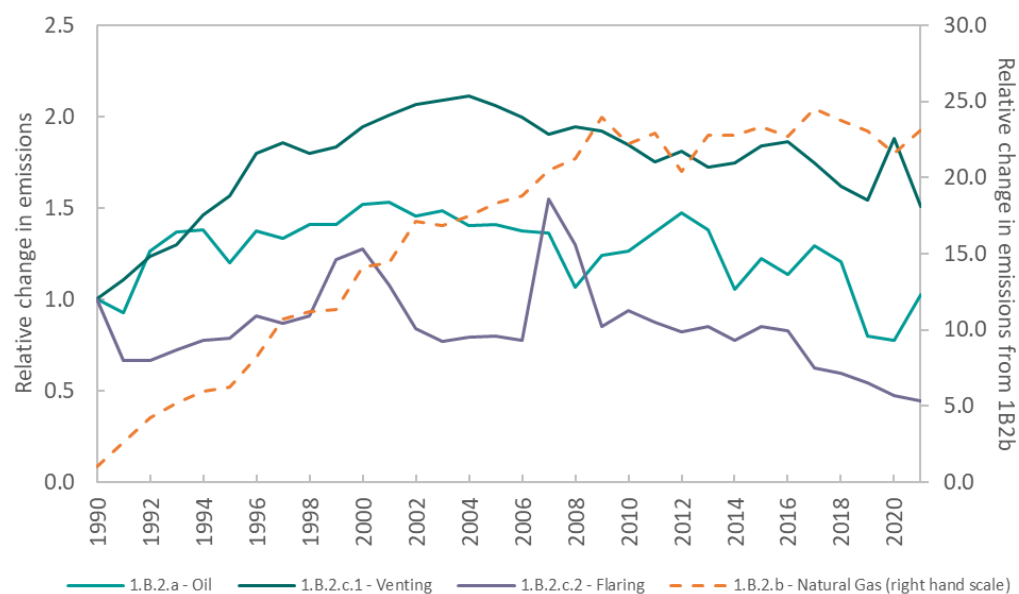


Figure 3-15. Relative change in 1.B.2 Fugitive emissions in CO<sub>2</sub> equivalents from oil and gas related activities. 1990=1. Source: Statistics Norway/Norwegian Environment Agency

### 3.4.1.2 Emissions from flaring in oil and gas exploration and production

In 2021, CO<sub>2</sub> equivalents emissions from flaring offshore contributed with 2% to the total GHG emissions in Norway. The emissions were 68% lower in 2021 than in 1990, whereas the oil and gas production was 86% higher (Figure 3-16). The reduction in emissions from flaring is partly explained by the introduction of tax on gas flared offshore from 1991 and by the prohibition of flaring offshore for other than safety reasons. The amount of gas flared may fluctuate from year to year due to variation of start-ups, maintenance, and interruption in operation. To minimize emissions from venting and flaring technical measures have been implemented. The venting rate is low due to strict security regulations. The leap in emissions from offshore flaring in 1999-2001 occurred because several oil/gas fields came into production in that period. The increase in emissions from flaring in 2007-2008, as seen in Figure 3-15, was due to start-up problems at a new LNG plant.

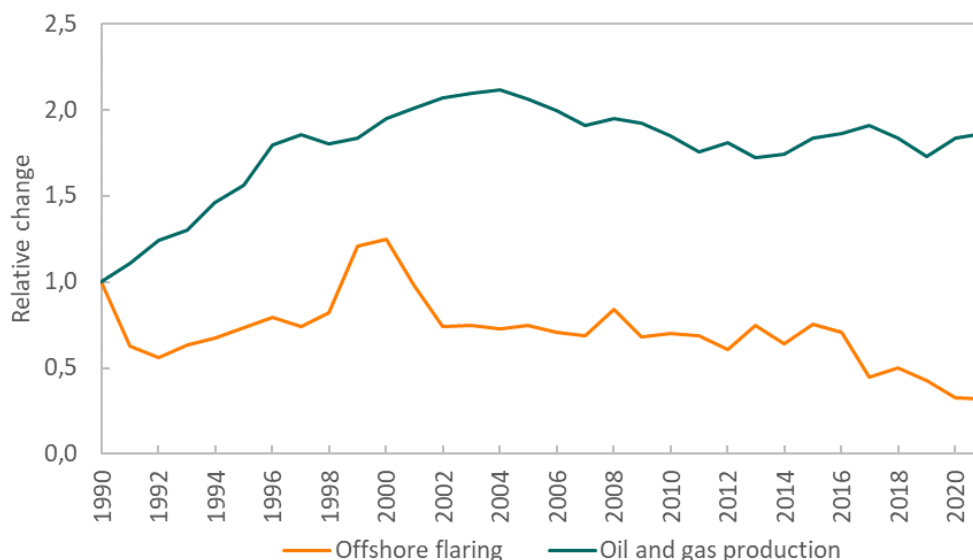


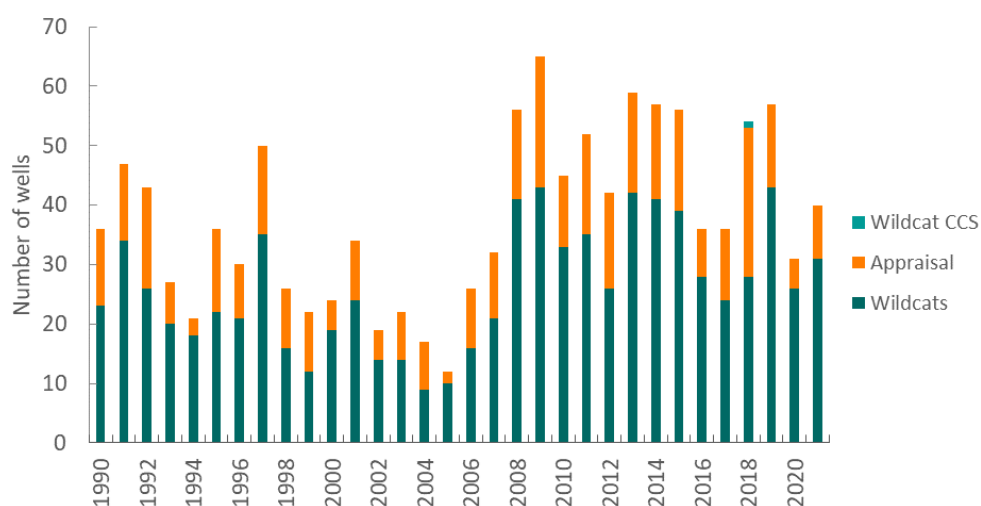
Figure 3-16. Relative change in CO<sub>2</sub> emissions from flaring offshore and total production of oil and gas (including NGL and condensate). 1990-2021. 1990=1. Source: Statistics Norway/Norwegian Environment Agency

### 3.4.1.3 Number of exploration and development wellbores

Figure 3-17 shows the number of exploration wellbores on the Norwegian continental shelf in the period 1990-2020 (by year entered/spudded). In average, 38 exploration wells have

been drilled each year from 1990. The timeseries for all exploration wellbores is reported in under 1B2a1 Exploration (oil) and therefore IE is reported in 1B2b1 Exploration (gas).

The total numbers of development wellbores (production, observation, and injection and injection for CCS; by year entered/spudded) are shown in Figure 3-18.



*Figure 3-17. Exploration wellbores. Number of wildcats, appraisal wells and wildcats for CCS. 1990-2021. Source: Norwegian petroleum directorate*

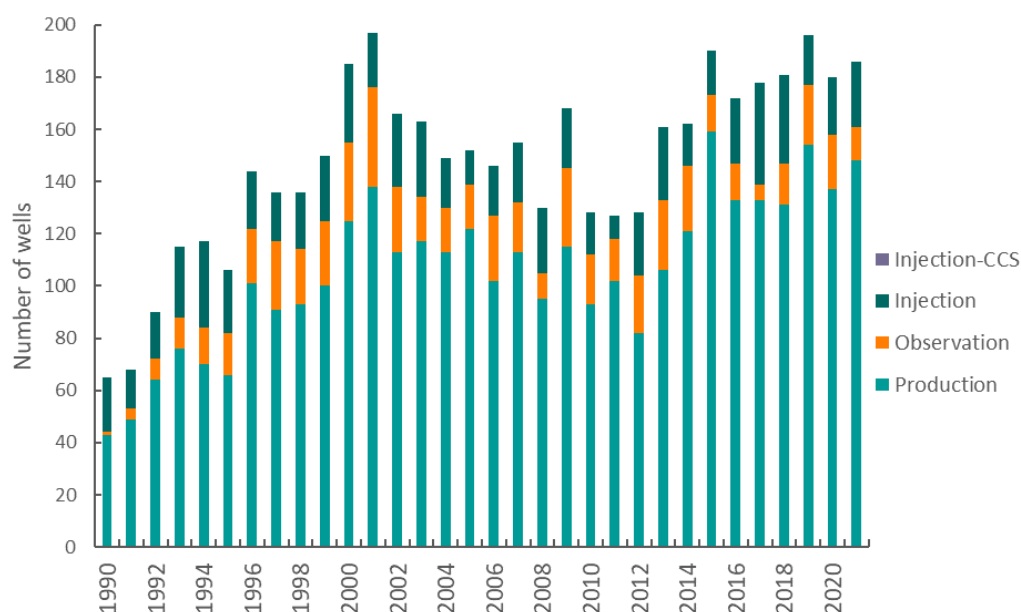


Figure 3-18. Development wellbores. Number of production, observation, and injection wells, as well as injection wells for CCS. 1990-2021. Source: Norwegian petroleum directorate

#### 3.4.1.4 Overall description of methodology for fugitive emissions from fuels

Table 3.28 gives an overview over methodology (tier), EF and AD for each source category within the sector used in the calculations of the fugitive emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and NMVOC. The table shows if the EF and/or AD used in the calculation are CS or PS. The notation R/E in the table indicates that emission estimates is based on reporting from the entities (R) or calculated (E) by Statistics Norway; see e.g., Section 3.4.4.2 about flaring. Basically, emissions estimates up to about 2002 are carried out by Statistics Norway, whereas emissions from 2003 onwards are reported by the operators based on guidelines from the Norwegian oil and gas association (2021b).

Fugitive and vented emissions from oil and gas activities are included in 1.B.2.c Venting. Flaring emissions are reported in 1B.2.c Flaring and includes emissions from flaring at oil and gas fields offshore, gas terminals and refineries.

Fugitive emissions (gas leaks) from the following source categories are included in 1.B.2.c Venting, and therefore the notation key is IE in CRF:

- exploration and production of oil



- exploration, production/processing, and transmission of gas.

Table 3.29 shows the shares of total CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions in the sector that is based on reported emissions and estimates by the Statistics Norway in 2021. It can be seen that about 90% of the CH<sub>4</sub> and CO<sub>2</sub> emissions in the sector, included coal mining, are based on reports from the plants, mainly offshore installations. N<sub>2</sub>O is based on estimates performed by Statistics Norway.

#### 1.B.2.a Oil:

- CO<sub>2</sub>: 92% of the emissions in the source category are *reported emissions*. The emissions are from a catalytic cracker at one oil refinery and indirect CO<sub>2</sub> emissions from loading and storage of crude oil. The emissions from the latter source category are estimated based on reported emissions of NMVOC and CO<sub>2</sub>.
- CH<sub>4</sub>: 100% is based on *reports* from refineries and oil and gas installations.

#### 1.B.2.b Natural gas:

- CO<sub>2</sub>: 100% is *estimated* and is indirect CO<sub>2</sub> based on mostly reported CO<sub>2</sub> emissions from gas terminals
- CH<sub>4</sub>: 64% of the emissions is based on *reported* emissions from gas terminals.

#### 1.B.2.c Venting and flaring:

- CO<sub>2</sub>: 96% of the emissions are based on *reports* mostly from the oil and gas installations.
- CH<sub>4</sub>: 100% of the emissions are *reported* emissions from the oil and gas installations.

**Table 3.28 Fugitive emissions from oil and natural gas. Emission sources, compounds, methods, emission factors and activity data included in the Norwegian GHG Inventory.**

| <b>B Fugitive emissions from fuels</b> | <b>CO<sub>2</sub></b> | <b>CH<sub>4</sub></b> | <b>N<sub>2</sub>O</b> | <b>NMVOC</b> | <b>Method</b> | <b>Emission factor</b> | <b>Activity data</b> |
|----------------------------------------|-----------------------|-----------------------|-----------------------|--------------|---------------|------------------------|----------------------|
| <b>1.B.2.a Oil</b>                     |                       |                       |                       |              |               |                        |                      |
| <b>i. Exploration</b>                  | IE                    | IE                    | NO                    | IE           | Tier II       | CS                     | PS                   |
| <b>ii. Production</b>                  | IE                    | IE                    | NA                    | IE           | Tier II       | CS                     | PS                   |
| <b>iii. Transport</b>                  | E                     | R/E                   | NA                    | R/E          | Tier II       | CS                     | PS                   |
| <b>iv. Refining/Storage</b>            | R/E                   | R                     | NA                    | R            | Tier II       | CS                     | PS                   |
| <b>v. Distribution of oil products</b> | E                     | NA                    | NA                    | R/E          | Tier II       | C/CS                   | CS/PS                |
| <b>vi. Other</b>                       | NO                    | NO                    | NA                    | NO           |               |                        |                      |
| <b>1.B.2.b Natural gas</b>             |                       |                       |                       |              |               |                        |                      |
| <b>i. Exploration</b>                  | IE                    | IE                    | NA                    | IE           | Tier II       | CS                     | PS                   |
| <b>ii. Production</b>                  | IE                    | IE                    | NA                    | IE           | Tier II       | CS                     | PS                   |
| <b>iii. Processing</b>                 | IE                    | IE                    | NA                    | IE           | Tier II       | CS                     | PS                   |
| <b>iv. Transmission and storage</b>    | IE                    | IE                    | NA                    | IE           | Tier II       | CS                     | PS                   |
| <b>v. Distribution</b>                 | IE                    | E                     | NA                    | IE           | Tier II       | OTH                    | CS/PS                |
| <b>vi. Other</b>                       | E                     | R                     | NA                    | R            | Tier II       | CS                     | PS                   |
| <b>1.B.2.c</b>                         |                       |                       |                       |              |               |                        |                      |
| <b>Venting</b>                         |                       |                       |                       |              |               |                        |                      |
| <b>i. Oil</b>                          | IE                    | IE                    | NA                    | IE           | Tier II       | CS/PS                  | PS                   |
| <b>ii. Gas</b>                         | IE                    | IE                    | NA                    | IE           | Tier II       | CS/PS                  | PS                   |
| <b>iii. Combined</b>                   | R/E                   | R/E                   | NA                    | R/E          | Tier II       | CS/PS                  | PS                   |
| <b>Flaring</b>                         |                       |                       |                       |              |               |                        |                      |
| <b>i. Oil (well testing)</b>           | R/E                   | E                     | E                     | R/E          | Tier II       | CS                     | PS                   |
| <b>ii. Gas</b>                         |                       |                       |                       |              |               |                        |                      |
| <b>- Gas and oil fields</b>            | R/E                   | R/E                   | E                     | R/E          | Tier II       | CS                     | PS                   |
| <b>- Gas terminals</b>                 | R                     | R                     | E                     | R/E          | Tier I        | CS                     | CS                   |
| <b>- Refineries</b>                    | R                     | R                     | R/E                   | E            | Tier I        | CS                     | CS                   |
| <b>iii. Combined</b>                   | IE                    | IE                    | IE                    | IE           | Tier I        | CS                     | CS                   |

Directorate of Mining (2014)

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated by Statistics Norway (Activity data \* emission factor). IE = Included elsewhere, NO = Not occurring, CS = Country specific, PS = Plant specific, Tier = the qualitative level of the methodology used, C=Corinair, OTH=Other.*

**Table 3.29 Fugitive emissions from oil and natural gas. Share of total CH<sub>4</sub>, CO<sub>2</sub> and N<sub>2</sub>O emissions in the sector based on estimated and reported emission estimates for 2021.**

|                                         | CO <sub>2</sub> |          | CH <sub>4</sub> |          | N <sub>2</sub> O |          |
|-----------------------------------------|-----------------|----------|-----------------|----------|------------------|----------|
|                                         | Estimated       | Reported | Estimated       | Reported | Estimated        | Reported |
| <b>1B Fugitive emissions from fuels</b> | 8%              | 92%      | 19%             | 81%      | 100%             | 0%       |
| <b>1.B.1.a Coal Mining</b>              | 100%            | 0%       | 100%            | 0%       |                  | 0%       |
| <b>1.B.2.a Oil</b>                      | 8%              | 92%      | 0%              | 100%     |                  | 0%       |
| <b>1.B.2.b Natural gas</b>              | 100%            | 0%       | 36%             | 64%      |                  | 0%       |
| <b>1.B.2.c Venting and flaring</b>      | 4%              | 96%      | 0%              | 100%     | 100%             | 0%       |

Source: Statistics Norway/Norwegian Environment Agency

Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are reported separately in CRF Table 6.

### 3.4.2 Fugitive Emissions from Oil, 1.B.2.a (Key category for CO<sub>2</sub> and CH<sub>4</sub>)

#### 3.4.2.1 Description

1.B.2.a covers emissions from loading and storage of crude oil, refining of oil and distribution of gasoline. For 1.B.2.a.i Exploration and ii Production, see section 3.4.4.

Emissions from loading and storage of crude oil produced on the Norwegian continental shelf (NCS) are included in the Norwegian inventory. This includes oil loaded from oil fields that spans over both the Norwegian and United Kingdom's continental shelf when loading takes place on the Norwegian part of the shelf.

Loading and storage of crude oil on the oil fields offshore and at oil terminals onshore causes direct emissions of CH<sub>4</sub> and indirect emissions of CO<sub>2</sub> from oxidized NMVOC and CH<sub>4</sub>. Non-combustion emissions from Norway's oil refineries include CO<sub>2</sub>, CH<sub>4</sub> and NMVOC. It is important to have in mind that the source category 1.B.2.a.iv also includes CO<sub>2</sub> emissions from catalyst regeneration (coke burn off) at the catalytic cracker at one refinery, see section 3.4.1.1. Gasoline distribution causes emissions of NMVOC, which lead to indirect CO<sub>2</sub> emissions.

Particularly during loading of ships with oil and refined petroleum products, volatile organic compounds (VOCs) are released from the ship's cargo tanks to the atmosphere.

When shuttle tankers are loaded with oil from offshore installations, the atmosphere

originally present in the empty cargo tanks will be evacuated as the oil is filled. The evacuated gas contains VOC-gas originally in the tanks prior to filling and VOC-gas that is evaporated from the loaded oil. A considerable effort has been made in reducing the possibility for such evacuated VOC gas to be emitted to atmosphere. This has resulted in several technologies implemented for VOC treatments on the ships. About 20 ships are used for in the Norwegian sector. Each ship is equipped with a VOC treatment system. The selected system varies from ship to ship.

Fugitive emissions from oil (1B2a) is key category for CO<sub>2</sub> and CH<sub>4</sub>, both level and trend, following both approach 1 and 2.

### 3.4.2.2 Methodological issues

#### Loading and storage of crude oil offshore and onshore – 1.B.2.a.iii

The general method for calculating emissions of CH<sub>4</sub> and NMVOC from loading and storage of crude oil is:

*field specific amount of crude oil loaded and stored multiplied with field specific emission factors.*

For the years 1990-2002 the emissions of CH<sub>4</sub> and NMVOC is calculated by Statistics Norway. The calculation is based on the field specific amounts of crude oil loaded and stored multiplied with field specific emission factors. Field specific activity data and emission factors used in the calculation were annually reported by the field operators. Since year 2000 an increasing share of the shuttle tankers have had installed vapor recovery units (VRU), and emissions from loading of crude oil on shuttle tankers with and without VRU are calculated separately for each field. In addition, emission figures were annually reported to the Norwegian Environment Agency and used in the QC of the emission figures calculated by Statistics Norway.

From 2003, emissions of CH<sub>4</sub> and NMVOC from loading and storage of crude oil on shuttle tankers included in the GHG Inventory are based on reported emission figures from the oil companies. Emissions, activity and emissions factors with and without VRU are reported from each field operator into the database Footprint. The database is operated by Offshore Norway (the employer and industry organization for companies with activities related with the Norwegian continental shelf). Although the method of obtaining data changed in 2002, the figures will be comparable with the corresponding ones for 1990-2002.

An agreement was established 25 June 2002 between the Norwegian Pollution Control Authority (now Norwegian Environment Agency) and the VOC Industrial cooperation (a

union of oil companies operating on the Norwegian continental shelf) aiming to reduce NMVOC emissions from loading and storage of crude oil offshore. Although the method of obtaining data changed in 2002, the figures will be comparable with the corresponding ones for 1990-2002A programme on measurement and calculation to quantify emissions of methane and NMVOC from ship loading of crude oil has been established within the VOC Industrial cooperation. The annual report from the VOC Industrial cooperation shall explain, how the emissions are distributed on the individual loading points and how the emissions have been measured /calculated. Uncertainty in reported values must be determined and reported.

Norway considers the method for calculating the CH<sub>4</sub> and NMVOC emissions from loading and storage of crude oil is consistent for the period 1990-2021.

For the two Norwegian oil terminals onshore, the emissions from loading of crude oil are reported annually from the terminals to the Norwegian Environment Agency. At one of the terminals, a VRU for recovering NMVOC was installed in 1996, and at the other, a VRU was installed in 2008. The efficiencies of the VRU's are about 80% and 90%, respectively. The calculation of the emissions of CO<sub>2</sub>, CH<sub>4</sub> and NMVOC at both terminals is based upon the amount of crude oil loaded and oil specific emission factor dependent of the origin of the crude oil loaded.

The reported indirect CO<sub>2</sub> emissions from the oxidation of CH<sub>4</sub> and NMVOC in the atmosphere for this source category is calculated by Statistics Norway, see Chapter 9.

#### Refining/Storage – 1.B.2.a.iv

The direct emissions of CO<sub>2</sub>, CH<sub>4</sub> and NMVOC included in the inventory are reported by the refineries to the Norwegian Environment Agency. The direct CO<sub>2</sub> emissions reported in this sector originate from catalyst regeneration (coke burn-off) in the catalytic cracking unit and the coke calcining kilns at one refinery. The emissions from the catalytic cracker are included in the Norwegian ETS and the emissions reported in source category 1.B.2.a.iv is from the ETS and is therefore regarded being of high quality. The CO<sub>2</sub> emissions from catalytic cracker and calcining kilns are calculated from the formula:

$$\text{tonne CO}_2 \text{ per year} = ((\text{Nm}^3 \text{ RG per year} * \text{volume\% CO}_2) / 100 * (\text{molar weight of CO}_2 / 22.4)) / 1000$$

- the amount of stack gas (RG) is measured continuously
- the density of the stack gas is 1.31 kg/Nm<sup>3</sup>
- volume percentage of CO<sub>2</sub> is based on continuously measurements. However, if the refinery can document that the volume percentage of CO<sub>2</sub> is not fluctuating more

than 2% from last year report it is not mandatory to have continuous measurements.

Statistics Norway calculates the indirect CO<sub>2</sub> from oxidized CH<sub>4</sub> and NMVOC.

#### Gasoline distribution – 1.B.2.a.v

NMVOC emissions from gasoline distribution are calculated from the amount of gasoline sold and emission factors for loading of tankers at gasoline depot, loading of tanks at gasoline stations and loading of cars.

### **3.4.2.3 Activity data**

#### Loading and storage of crude oil offshore and onshore – 1.B.2.a.iii

The amount of oil buoy loaded and stored on vessels on the NCS is reported by the field operators into the Footprint database and in an annual report to the Norwegian Environment Agency (NEA) and the Norwegian Petroleum Directorate. From 2003 and onwards, the inventory is based on data reported through the Footprint system.

Before 2003, Statistics Norway gathered data on amounts of crude oil loaded at shuttle tankers and stored on storage vessels from the Norwegian Petroleum Directorate. The data from each field are reported monthly by the field operators to the Norwegian Petroleum Directorate on both a mass and a volume basis. The allocation of the amount of crude oil loaded at shuttle tankers and stored at storage vessels with or without VRU comes from the annual report which the field operators are required to deliver to the Norwegian Environment Agency and the Norwegian Petroleum Directorate.

The amount of oil loaded at onshore oil terminals is also reported annually to the Norwegian Environment Agency and the Norwegian Petroleum Directorate.

The amount of crude oil buoy loaded and stored on vessels offshore and crude oil loaded and unloaded at an onshore oil terminal is reported for all years in source category 1.B.2.a.iii, as recommended by ERT in previous review reports.

#### Refining – 1.B.2.a.iv

The crude oil refined included in the CRF is crude oil converted in refineries from the Energy balance.

#### Gasoline distribution – 1.B.2.a.v

Gasoline sold is annually collected in Statistics Norway's sale statistics for petroleum products.

### 3.4.2.4 Emission factors

#### Loading and storage of crude oil offshore and onshore

From 1990 to 2002 emission factors used in the calculation of CH<sub>4</sub> and NMVOC emissions from loading and storage of crude oil offshore and onshore were field/plant specific and were reported to the Norwegian Environment Agency and the Norwegian Petroleum Directorate in an annual report. The Norwegian Environment Agency forwarded the emission factors to Statistics Norway that calculated the emissions. From 2003, the inventory is based on reported emissions from the operators using field-specific factors (see section 3.4.2.2).

The evaporation rate varies from field to field and over time, and the emission factors are dependent on the composition of the crude oil as indicated by density and Reid vapour pressure (RVP). The VOC evaporation emission factors are obtained from measurements, which include emissions from loading and washing of shuttle tankers. For some fields the emission factors are not measured, only estimated. The CH<sub>4</sub> content of the VOC evaporated is also measured so that total emissions of VOC are split between CH<sub>4</sub> and NMVOC.

The emission factors used by the field operators in their calculations is reported to the Norwegian Environment Agency and the Norwegian Petroleum Directorate. They report factors with and without VRU and the split between CH<sub>4</sub> and NMVOC. The emission factors are reported by the field operators into the database Footprint.

*Loading on shore:* Norway's two oil terminals have both installed VRUs, which reduce NMVOC emissions from loading of ships at the terminals by about 80–90%. However, the VRU technology is not designed to reduce methane and ethane emissions.

#### Refining/Storage – 1.B.2.A.iv

The CO<sub>2</sub> emissions from the catalytic cracker during catalyst regeneration are calculated as described above under Methodological issues. The CO<sub>2</sub> IEF in CRF is calculated from the emissions from catalytic cracking at one refinery and the amount of crude oil refined at all refineries.

The emission factor used in the calculation of methane emissions from the largest refinery is based upon measurements using DIAL (Differential absorption LIDAR). A new measurement program was initiated in 2009. An annual EF is deduced from the measured methane emissions and the crude oil throughput. The average EF for the period 2009-2013 is used for the years before the current program was initiated, *i.e.* 1990-2008.

#### Gasoline distribution – 1.B.2.a.v

Emission factor for NMVOC from filling gasoline to cars used in the calculations are from EEA (2001) and is 1.48 kg NMVOC/tonne gasoline.

#### **3.4.2.5 Uncertainties and time-series consistency**

The uncertainty in the emission factors of methane from *oil loading* (Rypdal & Zhang 2000) and NMVOC (Rypdal & Zhang 2001) is estimated to be  $\pm 40\%$  and in the activity data  $\pm 3\%$ .

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **3.4.2.6 Source-specific QA/QC and verification**

Statistics Norway gathers data for the amount of crude oil loaded off- and onshore from the Norwegian Petroleum Directorate. These data are reported monthly by the field operators to the Norwegian Petroleum Directorate. The activity data are quality controlled by comparing them with the figures reported in the field operator's annual report to the Norwegian Environment Agency and the Norwegian Petroleum Directorate. We have not found any discrepancy of significance between the data from the two data sources.

Statistics Norway's calculated emissions for 1990-2002 are compared with the emission data that the field operators report to the Norwegian Environment Agency and the Norwegian Petroleum Directorate. We have not found any discrepancy of significance between the two emission calculations.

From 2003 the Norwegian Environment Agency annual compare data annually reported into the Footprint reporting tool by the oil field operators with data from the annual report from the VOC Industry Cooperation. If discrepancies are found between the two sets of data, they are investigated, and corrections are made if appropriate. If errors are found, the Norwegian Environment Agency contacts the plant to discuss the reported data and changes are made if necessary.

#### **3.4.2.7 Category-specific recalculations**

- *Reallocation:* Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

#### **3.4.2.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.



### 3.4.3 Fugitive Emissions from Natural Gas, 1.B.2.b (Key category for CH<sub>4</sub>)

#### 3.4.3.1 Description

Sector 1.B.2.b covers fugitive emissions of CH<sub>4</sub> and NMVOC and indirect emissions of CO<sub>2</sub> from the two gas terminals and emissions from *distribution* of natural gas. For 1.B.2.b.i Exploration, ii Production and iii Processing, see section 3.4.4.

The Norwegian gas system has two main parts: The extraction and export sector, including processing terminals and transmission pipelines handling large gas volumes, and a much smaller domestic network. Emissions from transmission, distribution and storage within the main extraction/export system is reported in 1.B.2.b vi Other. Emissions from the domestic system is reported in 1.B.2.b v Distribution.

The rationale for this allocation is that emissions from transmission and storage in the extraction and export sector cannot be split from emissions from extraction and processing emissions at integrated facilities. The emissions from the domestic system might be split. However, the data in 1.B.2.b.iv *Transmission and storage* would then be misleading, as it would cover only a small fraction of Norwegian emissions for this activity. Thus, emissions from 1.B.2.b.iv are reported as "included elsewhere".

CH<sub>4</sub> from natural gas is according to Approach 2 *key category* with respect to trend.

#### 3.4.3.2 Methodological issues

##### Gas terminals

Fugitive emissions of CH<sub>4</sub> and NMVOC from gas terminals are reported annually to the Norwegian Environment Agency.

Emissions from gas terminals includes CH<sub>4</sub> and NMVOC and hence indirect CO<sub>2</sub>. The methane and NMVOC emissions are either caused by point sources (e.g., dedicated natural gas vents, wastewater treatment plants, storage tanks and loading of hydrocarbon products on vessels), by diffuse emission from valves, fittings and instruments in the hydrocarbon containing process systems, or from accidental leakages.

The emissions are calculated based on monitoring and/or calculation. Diffuse emissions from equipment units are recorded in the leak detection and maintenance program. The number of sealed and leaky equipment units is collected two times a year and the average number of the counting is used in the calculation. It is assumed in the calculation figures that a leakage has lasted the whole year if not the opposite is documented.

### Gas distribution

Norway has chosen to calculate data for gas transmission and distribution based on the default emission factor from the IPCC 2006 Guidelines. This was decided as conclusion to the discussion with the expert review team during the review of NIR 2016.

Only emissions of CH<sub>4</sub> are reported in 1.B.2.b.v. CO<sub>2</sub> emissions are reported as "included elsewhere". According to the energy statistics, the total consumption data refer to amounts fed into the domestic transmission and distribution systems. The same activity data are used for calculating emissions from combustion of the natural gas. Any carbon leakage before combustion would thus be included as CO<sub>2</sub> in the combustion emissions in 1A. This applies to both direct emissions of CO<sub>2</sub> and indirect CO<sub>2</sub> emissions from CH<sub>4</sub> leakage. Direct emissions of CO<sub>2</sub> are likely to be very small: Using the default values from IPCC (2006) they would be 25 tonnes or less throughout the time series. There was no activity in this sector until 1994.

#### **3.4.3.3 Activity data**

Activity data are sampled through the terminals' measuring and maintenance program, which purpose is to reduce leakage.

### Gas distribution

Data on use of natural gas from the energy statistics are used. From the total domestic consumption including energy sectors the following consumption is excluded:

- Consumption in the gas extraction and processing industry, offshore and onshore, for which emissions from transport is included in 1.B.2.b.vi *Other*
- Consumption for methanol production, for which emissions from transport is included in 2.B.8.a *Methanol*. The plant has its own gas pipeline from an offshore gas field, and emissions from transmission is included with other process emissions at the plant.

The remaining consumption of natural gas is distributed to final consumption by pipeline or LNG systems. An increasing fraction of the consumption is LNG.

The same activity data are used for transmission and distribution. The factors from IPCC (2006) shown below actually refer to amount of *marketable gas* (transmission/storage) and *utility sales* (distribution).

#### **3.4.3.4 Emission factors**

### Gas distribution

Emission factors from IPCC (2006) are used for the emission estimates, as shown in Table 3.30. The factors refer to pipeline distribution. As no tier 1 methodology was available for

LNG distribution, and data for a tier 2 or 3 approach could not be obtained within the available time frame, the factors are used for all Norwegian activity as defined above.

**Table 3.30 Emission factors for gas distribution.**

| Category                            | Subcategory  | Emission source | Value                | Selected value | Uncertainty |
|-------------------------------------|--------------|-----------------|----------------------|----------------|-------------|
| <b>Gas Transmission and Storage</b> | Transmission | Fugitives       | 6.6 E-05 to 4.8 E-04 | 2.73 E-04      | ±100%       |
|                                     |              | Venting         | 4.4 E-05 to 3.2 E-04 | 1.82 E-04      | ±75%        |
|                                     | Storage      | All             | 2.5 E-05             | 2.5 E-05       | -20 - 500%  |
| <b>Gas Distribution</b>             | All          | All             | 1.1 E-03             | 1.1 E-03       | -20 - 500%  |

Source: IPCC (2006), vol 2 Energy, table 4.2.4

### 3.4.3.5 Uncertainties and time-series consistency

The uncertainty in the emission factors for fugitive methane from natural gas is estimated to be -50/+100%. The uncertainty in the activity data  $\pm 3\%$ .

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

### 3.4.3.6 Source-specific QA/QC and verification

Reported emissions are compared with previous years' emissions.

### 3.4.3.7 Category-specific recalculations

*Reallocation:* Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

### 3.4.3.8 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 3.4.4 Fugitive Emissions from Venting, 1.B.2.c Venting (Key category for CO<sub>2</sub> and CH<sub>4</sub>)

### 3.4.4.1 Description – Venting

This chapter describes fugitive emissions from venting and diffuse emissions from upstream oil and gas activities, which are currently all reported under sector 1.B.2.c. The annual emission inventory for *venting* and *diffuse emissions* from each petroleum facility is quantified (calculated) using methods for each individual source, see Table 3.31 and Table 3.32.

Norway will report emissions from venting and diffuse emissions separately in CRF table 1.B.2 from 2024. Furthermore, we will distinguish emissions between oil and gas sources. However, most petroleum facilities on the Norwegian continental shelf will handle a combination of oil and gas, and it is therefore challenging to truly differentiate between oil and gas extraction as sources of the emissions.

Venting and other emissions connected to CCS is reported in 1C. See Section 3.5 and Annex IV CO<sub>2</sub> capture and storage at the oil and gas production field Sleipner Vest and Hammerfest LNG (Snøhvit gas-condensate field) for description of this source.

The sector 1.B.2.c Venting (including fugitive emissions from oil and natural gas activities) includes emissions of CH<sub>4</sub> and NMVOC and hence indirect CO<sub>2</sub>. The methane and NMVOC emissions from the upstream oil and gas activity is either caused by dedicated natural gas vents, by fugitive (diffuse) emissions leaking out from valves, fittings and instruments in the hydrocarbon containing process systems, or from accidental leakages. The major source is cold venting of CH<sub>4</sub> and NMVOC.

Venting of CH<sub>4</sub> and NMVOC occurs at oil fields, gas fields and combined oil/gas fields and depends on planned system design and measures implemented.

To improve the understanding of fugitive emissions of methane and NMVOC from the upstream oil and gas facilities on the Norwegian Continental Shelf, the Norwegian Environment Agency conducted a study in October 2014 to March 2016 (Add Novatech AS 2016a; Add Novatech AS 2016b; Add Novatech AS 2016c; Husdal et al. 2016). The production facilities on the Norwegian continental shelf were assessed individually to identify and map their respective sources of methane and NMVOC emissions.

Sources of fugitive emissions of hydrocarbon gases can be divided into two emission categories:

- a. **Diffuse emissions.** These are leaks of natural gas directly into the atmosphere through valves and seals, hoses, and flexible piping, as well as evaporation from hydrocarbon liquids and from cuttings. Diffuse emissions can never be fully eliminated but can be minimised by use of good/appropriate materials, equipment, and design, as well as through good operating procedures. Diffuse emissions can occur anywhere on the facility where there is hydrocarbon gas.

- b. **Venting/cold venting/cold flaring.** These emissions are hydrocarbon-containing gases, emanating from various processes or sub-processes at the facilities, and routed to the atmosphere as a result of planned and selected operational solutions. Emissions from *vents* are intentional and involve a dedicated pipe from which volatile hydrocarbons are released into the open air. Emissions from such vents can originate from one or more emission sources and would normally imply a planned system design, i.e., being an integrated part of the facility's construction. Venting (direct emissions) as a solution may be selected for several reasons; safety issues, high levels of inert gases (mainly nitrogen) in the gas, pressure conditions of the facility or purely cost-related preferences (very expensive to eliminate/reduce emissions relative to the amount of emissions) or a combination of this. In many cases venting can be avoided by good design. The options may be recycling of gas or flaring. Environmentally, recycling is the best solution, but flaring may be preferable because the greenhouse effect of the products of combustion are significantly lower than for hydrocarbon gases. Some of the operational emissions of hydrocarbon gases are more or less impossible to eliminate because technical solutions are not available or because potential solutions are very costly.

Many of emissions from the predominant emission sources can theoretically be recycled. The study has shown that recovery of such waste gases is a well-proven technique. Recovery is the chosen disposal solution for many of these emission sources on some installations. Technical or cost-related restrictions on the facilities without recovery may have made such action unfavourable.

Individual permits pursuant to the Pollution Control Act regulate all offshore oil and gas fields. Installations built after 2005 have specific methane emission limit values (ELV) in their permits. NEA has started a process aiming to set methane ELVs in permits for installations built before 2005, since we now have sufficiently good emission data based on a new reporting regime implemented in 2017, ref. section 3.4.1.2.

The operators of oil and gas fields at the Norwegian Continental Shelf report their emissions to NEA on annual basis (according to requirements in the "HSE-regulations"). The HSE-regulations can be downloaded from the websites of the Petroleum Safety Agency: [PDFs of regulations \(ptil.no\)](https://ptil.no). The reporting is mandatory and regulated by the Norwegian Pollution Control Act and associated official guidelines (M-107) issued by NEA.

Section 34 c of the "Management regulation" deals with reporting to NEA:

c) annual report in accordance with the Norwegian Environment Agency's *Guidelines for reporting from the petroleum activities offshore (M-107) (in Norwegian only)*. Deadline for reporting is the 15<sup>th</sup> of March the following year. The reporting shall take place using the

Footprint reporting tool. Complete quality assured reports and underlying data shall be available for the Norwegian Environment Agency before expiration of the reporting deadline.

CH<sub>4</sub> and CO<sub>2</sub> from venting and flaring is according to Approach 1 and 2 *key category* with respect to both level and trend.

#### **3.4.4.2 Methodological issues - Venting**

Emissions of CH<sub>4</sub> and NMVOC from cold venting and diffuse emissions for each field are reported annually to the Norwegian Environment Agency from the field operators. The indirect CO<sub>2</sub> emissions are calculated by Statistics Norway.

A new method for calculation and reporting of venting and diffuse emissions from offshore oil and gas production fields is used in the field operators annual report from 2017 onwards. For the years 1990-2016 recalculated emission estimates were reported in NIR 2020. The new timeseries is assumed to be consistent throughout the reporting period. The method for 1990-2016 is explained at the end of this sub-chapter. First, we will explain the new method for estimation and reporting of emissions.

##### Methodology for quantifying the emissions from venting and diffuse emissions 2017-present

The method used for quantifying fugitive emissions from Norwegian offshore oil and gas production has recently been reviewed. Fugitive emissions of methane are calculated using a so-called "bottom-up" method.

To improve the understanding of fugitive emissions of methane and NMVOC (i.e. cold venting and diffuse emissions) from the upstream oil and gas facilities on the Norwegian Continental Shelf, the Norwegian Environment Agency conducted a study in October 2014 to March 2016 (Add Novatech AS 2016a; Add Novatech AS 2016b; Add Novatech AS 2016c; Husdal et al. 2016).

"All" potential sources were registered during the survey, regardless of the magnitude of their emissions, because it is as important to document that a source is small (or negligible) as it is to document that it is large. As a result, several "new" emission sources not covered in the old reporting regime were identified. Of equal importance was the discovery that many of the "old" sources consist in reality of several partly or fully independent sub-sources. The survey identified the importance of splitting some sources into such sub-

sources – partly because the waste gas they emit was handled differently and partly because some of the sub-sources account for significant emission quantities.

The survey also established that some of the "new" sources/processes have historically been under the operator's radar. This may explain why information available from the operator for evaluating emissions from these sources was less relevant than for sources which had previously been in focus

The study identified a total of 48 potential sources (Add Novatech AS 2016b). This is partly because the 13 former emission sources have been broken down into sub-sources and partly because new sources have been identified. The contribution from several of the "new" emission sources was found to be insignificant.

Based on the outcome of the study, dedicated methodologies were recommended for the individual emission sources (and sub-sources), see Table 3.31. Generic methods (GM) are recommended to ensure consistency in the calculation over time and across facilities. However, facility specific quantification methods (FSM) are recommended for some processes. The latter applies particularly to emission sources with such great variations and complexity that generic methods might easily yield inaccurate results, and to those found only on one or a few facilities, see Table 3.31. Note that table 3.6 contains methods for 34 sources, rather than 43, as emissions from the remaining 9 sources are handled as a general addition to the emissions from an installation, as recommended by (Husdal et al. 2016).

For some processes/sub-processes, a combination of emission factors and activity factors was recommended. The activity factor which controls emissions could, for example, be produced water volume and the number of wellbores. Otherwise, the methods may vary widely:

- measurement/sampling
- process simulations / use of special computer programmes
- utilising available registered measurement data
- logging of incidents (for batch emissions)
- supplier data

**Table 3.31 Identified potential emission sources and overview of proposed emission quantification methods. GM=Generic method, FSM=facility specific method.**

| Source ID | Main source                           | Sub source                                    | Method category | General definition                                                 |
|-----------|---------------------------------------|-----------------------------------------------|-----------------|--------------------------------------------------------------------|
| 1.1       | Measured emissions                    | Measured common vent                          | GM              | Waste gas metering/determining flow rate                           |
| 10.1      | Triethyleneglycol (TEG) regeneration  | TEG degassing tank                            | FSM             | Dedicated computer programme (GRI-GLYCalc, for example)            |
| 10.2      | Triethyleneglycol (TEG) regeneration  | TEG regenerator                               | GM              | Analysis of TEG solution, alternatively the GRI-CLYCalc software   |
| 10.3      | Triethyleneglycol (TEG) regeneration  | Stripping gas                                 | GM              | Stripping gas flow rate                                            |
| 20.1      | Monoethyleneglycol (MEG) regeneration | MEG degassing tank                            | GM              | Recognised comptuer programmes (GRI-GLYCalc, MultiPro Scale, etc.) |
| 20.2      | Monoethyleneglycol (MEG) regeneration | MEG regenerator                               | GM              | Recognised comptuer programmes (GRI-GLYCalc, MultiPro Scale, etc.) |
| 20.3      | Monoethyleneglycol (MEG) regeneration | Stripping gas                                 | GM              | Stripping gas flow rate                                            |
| 30.1      | Amine regeneration                    | Amine degassing tank                          | FSM             | Established by each operator                                       |
| 30.2      | Amine regeneration                    | Amine regenerator                             | FSM             | Established by each operator                                       |
| 40.1      | Produced water handling               | Produced water degassing tank                 | GM              | Based on the pressure reduction and produced water volume          |
| 40.2      | Produced water handling               | Flotation tank / CFU                          | GM              | Based on the upstream pressure and produced water volume           |
| 40.3      | Produced water handling               | Flotation gas                                 | GM              | Hydrocarbon flotation gas flowrate                                 |
| 40.4      | Produced water handling               | Discharge caisson                             | GM              | Based on the upstream pressure and produced water discharge volume |
| 50.1      | Centrifugal compressor sealant oil    | Degassing pots                                | FSM             | Established by each operator                                       |
| 50.2      | Centrifugal compressor sealant oil    | Sealing oil retention tank                    | FSM             | Established by each operator                                       |
| 50.3      | Centrifugal compressor sealant oil    | Sealing oil storage tank                      | FSM             | Established by each operator                                       |
| 60.1      | Pistonne compressor                   | Separator chamber                             | FSM             | Simulations, vendor data, etc.                                     |
| 60.2      | Pistonne compressor                   | Crank shaft housing                           | FSM             | Simulations, vendor data, etc.                                     |
| 70.1      | Dry compressor seals                  | Primary seal gas                              | GM              | Seal gas metering/supplier data                                    |
| 70.2      | Dry compressor seals                  | Secondary seal gas                            | GM              | Seal gas metering/supplier data                                    |
| 70.3      | Dry compressor seals                  | Leakage of primary seal gas to secondary vent | GM              | Seal gas metering/supplier data                                    |
| 80.1      | Flare gas that does not burn          | Extinguished flare and ignition of flare      | GM              | Logging of time with unignited flaring/flare gas metering          |



|              |                                      |                                                |     |                                                    |
|--------------|--------------------------------------|------------------------------------------------|-----|----------------------------------------------------|
| <b>80.2</b>  | Flare gas that does not burn         | Non-flammable flare gas                        | FSM | Established by each operator                       |
| <b>80.3</b>  | Flare gas that does not burn         | Inert gas flushed open flare                   | GM  | Flare gas metering                                 |
| <b>90.1</b>  | Leaks in the process                 | Larger gas leaks                               | GM  | Emission rate, duration, volume (current practice) |
| <b>90.2</b>  | Leaks in the process                 | Small gas leaks                                | GM  | OGI "leak/no leak" method                          |
| <b>100.1</b> | Purge and blanket gas                | Purge and blanket gas                          | GM  | Purge/blanket gas metering/flow rate determination |
| <b>110.1</b> | Gas analysers and test stations      | Gas analysers and test stations                | GM  | Slipstream flowrate                                |
| <b>120.1</b> | Drilling                             | Drilling                                       | GM  | Emission factor per completed wellbore             |
| <b>130.1</b> | Storage tanks for crude oil at FPSOs | Gas freeing in connection with tank inspection | GM  | Storage tank volume                                |
| <b>130.2</b> | Storage tanks for crude oil at FPSOs | Abnormal operating situation                   | FSM | Established by each operator                       |
| <b>140.1</b> | Gas freeing of process systems       | Gas freeing of process systems                 | GM  | Volume of process plant                            |
| <b>900.1</b> | General addition                     | FPSO                                           | GM  | Percentage of other emissions                      |
| <b>910.1</b> | General addition                     | Fixed facilities                               | GM  | Percentage of other emissions                      |

Source: Add Novatech AS (2016c) and Norwegian Oil and Gas (2021a)

The oil and gas production facilities on the Norwegian continental shelf have been assessed individually to identify and map their respective sources of methane and NMVOC emissions.

The annual emission inventory for *venting* and *diffuse emissions* from each petroleum facility is quantified (calculated) using recommended methods for each individual source (Husdal et al. 2016; Norwegian Oil and Gas 2021a). For some vents, the emissions are measured using flow meters. Emissions that cannot be measured are determined by means of emission factors, by process simulation or by using tailormade software or by other adequate methods. All quantification methods used to establish vented methane emission inventories are subject to significant uncertainties, spanning from a few percent to several tens of percent for single sources. The largest percentages of uncertainty are those for emission sources with small emissions.

*Diffuse emissions* (leaks of natural gas directly into the atmosphere) are quantified according to the "OGI leak / no leak" method, where high-sensitivity IR cameras are used to detect small gas leaks (see subchapter 3.11.2 in Norwegian Oil and Gas (2021a)). All the

facilities on the NCS are scanned with such cameras on an annual or semi-annual basis. This is also the case for the onshore oil and gas facilities (refineries and gas terminals).

The Norwegian Environment Agency is in a continuous dialogue with the industry to identify potentials for improvement and further work on optimizing the methodology used.

Table 3.31, Table 3.32 and Table 3.33 illustrate the details in the annual report from the operators based on the study (Add Novatech AS 2016a; Add Novatech AS 2016b; Add Novatech AS 2016c; Husdal et al. 2016). Small discrepancies between CRF data and these tables are due to difference in updating status, etc.

| <b>Table 3.32 Venting emissions from offshore oil and gas production in 2021.</b> |                                       |                               |                                          |                                 |                                                                      |
|-----------------------------------------------------------------------------------|---------------------------------------|-------------------------------|------------------------------------------|---------------------------------|----------------------------------------------------------------------|
| <b>Source ID</b>                                                                  | <b>Main source</b>                    | <b>Sub source</b>             | <b>CH<sub>4</sub> emissions (tonnes)</b> | <b>nmVOC emissions (tonnes)</b> | <b>Emissions of CO<sub>2</sub> equivalents (tonnes)<sup>10</sup></b> |
| <b>1.1</b>                                                                        | Measured emissions                    | Measured common vent          | 2155                                     | 2825                            | 66028                                                                |
| <b>10.1</b>                                                                       | Triethyleneglycol (TEG) regeneration  | TEG degassing tank            | 0                                        | 0                               | 0                                                                    |
| <b>10.2</b>                                                                       | Triethyleneglycol (TEG) regeneration  | TEG regenerator               | 48                                       | 524                             | 2484                                                                 |
| <b>10.3</b>                                                                       | Triethyleneglycol (TEG) regeneration  | Stripping gas                 | 144                                      | 534                             | 5181                                                                 |
| <b>20.1</b>                                                                       | Monoethyleneglycol (MEG) regeneration | MEG degassing tank            | 0                                        | 0                               | 0                                                                    |
| <b>20.2</b>                                                                       | Monoethyleneglycol (MEG) regeneration | MEG regenerator               | 3                                        | 224                             | 569                                                                  |
| <b>20.3</b>                                                                       | Monoethyleneglycol (MEG) regeneration | Stripping gas                 | 0                                        | 210                             | 462                                                                  |
| <b>30.1</b>                                                                       | Amine regeneration                    | Amine degassing tank          | 0                                        | 0                               | 0                                                                    |
| <b>30.2</b>                                                                       | Amine regeneration                    | Amine regenerator             | 0                                        | 0                               | 0                                                                    |
| <b>40.1</b>                                                                       | Produced water handling               | Produced water degassing tank | 44                                       | 12                              | 1255                                                                 |
| <b>40.2</b>                                                                       | Produced water handling               | Flotation tank / CFU          | 188                                      | 47                              | 5324                                                                 |
| <b>40.3</b>                                                                       | Produced water handling               | Flotation gas                 | 0                                        | 0                               | 0                                                                    |

<sup>10</sup> Emissions of CO<sub>2</sub> equivalents include indirect CO<sub>2</sub> emissions from CH<sub>4</sub> and NMVOC, using conversion factors of 2,75 t CO<sub>2</sub>/t CH<sub>4</sub> and 2,2 t CO<sub>2</sub>/t NMVOC. The NMVOC conversion factor is a generic factor for indirect CO<sub>2</sub> calculations.

|               |                                      |                                                |      |      |        |
|---------------|--------------------------------------|------------------------------------------------|------|------|--------|
| <b>40.4</b>   | Produced water handling              | Discharge caisson                              | 1276 | 319  | 36099  |
| <b>50.1</b>   | Centrifugal compressor sealant oil   | Degassing pots                                 | 0    | 0    | 0      |
| <b>50.2</b>   | Centrifugal compressor sealant oil   | Sealing oil retention tank                     | 2    | 1    | 45     |
| <b>50.3</b>   | Centrifugal compressor sealant oil   | Sealing oil storage tank                       | 1    | 1    | 39     |
| <b>60.1</b>   | Pistonne compressor                  | Separator chamber                              | 25   | 25   | 757    |
| <b>60.2</b>   | Pistonne compressor                  | Crank shaft housing                            | 16   | 19   | 488    |
| <b>70.1</b>   | Dry compressor seals                 | Primary seal gas                               | 826  | 364  | 23731  |
| <b>70.2</b>   | Dry compressor seals                 | Secondary seal gas                             | 19   | 15   | 571    |
| <b>70.3</b>   | Dry compressor seals                 | Leakage of primary seal gas to secondary vent  | 240  | 228  | 7173   |
| <b>80.1</b>   | Flare gas that does not burn         | Extinguished flare and ignition of flare       | 259  | 317  | 7898   |
| <b>80.2</b>   | Flare gas that does not burn         | Non-flammable flare gas                        | 376  | 198  | 10864  |
| <b>80.3</b>   | Flare gas that does not burn         | Inert gas flushed open flare                   | 250  | 190  | 7347   |
| <b>100.1</b>  | Purge and blanket gas                | Purge and blanket gas                          | 126  | 84   | 3687   |
| <b>110.1</b>  | Gas analysers and test stations      | Gas analysers and test stations                | 23   | 12   | 661    |
| <b>130.1</b>  | Storage tanks for crude oil at FPSOs | Gas freeing in connection with tank inspection | 106  | 65   | 3080   |
| <b>130.2</b>  | Storage tanks for crude oil at FPSOs | Abnormal operating situation                   | 11   | 84   | 491    |
| <b>140.1</b>  | Gas freeing of process systems       | Gas freeing of process systems                 | 20   | 60   | 674    |
| <b>Totals</b> |                                      |                                                | 6159 | 6360 | 184907 |

*Reported by field operators*

| <b>Table 3.33 Diffuse emissions from offshore oil and gas production in 2021.</b> |                      |                   |                                          |                                 |                                                         |
|-----------------------------------------------------------------------------------|----------------------|-------------------|------------------------------------------|---------------------------------|---------------------------------------------------------|
| <b>Source ID</b>                                                                  | <b>Main source</b>   | <b>Sub source</b> | <b>CH<sub>2</sub> emissions (tonnes)</b> | <b>nmVOC emissions (tonnes)</b> | <b>Emissions of CO<sub>2</sub> equivalents (tonnes)</b> |
| <b>90.1</b>                                                                       | Leaks in the process | Larger gas leaks  | 0                                        | 0                               | 7                                                       |
| <b>90.2</b>                                                                       | Leaks in the process | Small gas leaks   | 324                                      | 315                             | 9688                                                    |
| <b>120.1</b>                                                                      | Drilling             | Drilling          | 53                                       | 53                              | 1597                                                    |
| <b>900.1</b>                                                                      | General addition     | FPSO              | 27                                       | 20                              | 789                                                     |
| <b>910.1</b>                                                                      | General addition     | Fixed facilities  | 61                                       | 66                              | 1831                                                    |
| <b>Totals</b>                                                                     |                      |                   | 465                                      | 454                             | 13912                                                   |

*Reported by field operators*

As an example, reported information from the Åsgard B facility is shown in Table 3.34. As can be read from the table, the operator reported methane emissions from all 34 identified sources (ref. Table 3.31). 26 of the sources had reported emissions of 0 tonnes, either because the source does not exist on this installation, because the installation has VOC recovery equipment installed for the source, or because emissions are included in a different source at this installation. For the remaining 9 sources, emissions larger than 0 are reported, and the methodologies used to measure or estimate these emissions are reported. The different methodologies are described in (Norwegian Oil and Gas 2021a) and further elaborated in (Husdal et al. 2016).

Using source 70.1 (ref. Table 3.32) as an example, the operator at Åsgard B reports that the methodology used is "Indirect measurements". Norwegian Oil and Gas (2021a) chapter 3.9.3 provides a description of three recommended methods for this source, where "Indirect measurements" corresponds to the secondary method. Husdal et al. (2016) chapter 4.5 provides the justification for the methods, as well as the emission factors. For source 50.2, the methodology used is "Other FISM". Norwegian Oil and Gas (2021a) chapter 3.7, recommends a Facility-specific method for this emission source. Husdal et al. (2016), chapter 4.4.5 provides the justification for the recommendation.

| <b>Table 3.34 Diffuse emissions from Åsgard B in 2021.</b> |                 |                    |                      |                    |                  |                                          |                                 |
|------------------------------------------------------------|-----------------|--------------------|----------------------|--------------------|------------------|------------------------------------------|---------------------------------|
| <b>Year</b>                                                | <b>Facility</b> | <b>Main source</b> | <b>Sub source</b>    | <b>Methodology</b> | <b>Source ID</b> | <b>CH<sub>4</sub> emissions (tonnes)</b> | <b>nmVOC emissions (tonnes)</b> |
| 2021                                                       | ÅSGARD B        | Measured emissions | Measured common vent | Direct measurement | 1.1              | 704                                      | 643                             |

|      |          |                                       |                                                |                                                          |       |       |        |
|------|----------|---------------------------------------|------------------------------------------------|----------------------------------------------------------|-------|-------|--------|
| 2021 | ÅSGARD B | Dry compressor seals                  | Primary seal gas                               | Indirect measurement                                     | 70.1  | 110,5 | 65     |
| 2021 | ÅSGARD B | Triethyleneglycol (TEG) regeneration  | TEG regenerator                                | MultiProScale                                            | 10.2  | 17,1  | 186    |
| 2021 | ÅSGARD B | Leaks in the process                  | Small gas leaks                                | OGI leak/no leak                                         | 90.2  | 9,9   | 9,9    |
| 2021 | ÅSGARD B | General addition                      | Fixed facilities                               | 1% general addition                                      | 910.1 | 8,505 | 9,1356 |
| 2021 | ÅSGARD B | Produced water handling               | Discharge caisson                              | Based on the upstream pressure and produced water volume | 40.4  | 5,4   | 1,3    |
| 2021 | ÅSGARD B | Monoethyleneglycol (MEG) regeneration | MEG regenerator                                | MultiProScale                                            | 20.2  | 2,2   | 7,6    |
| 2021 | ÅSGARD B | Flare gas that does not burn          | Extinguished flare and ignition of flare       | Other FSM                                                | 80.1  | 1,2   | 0,7    |
| 2021 | ÅSGARD B | Centrifugal compressor sealant oil    | Sealing oil retention tank                     | Other FSM                                                | 50.2  | 0,218 | 0      |
| 2021 | ÅSGARD B | Amine regeneration                    | Amine degassing tank                           | Recycled                                                 | 30.1  | 0     | 0      |
| 2021 | ÅSGARD B | Amine regeneration                    | Amine regenerator                              | Included in common vent                                  | 30.2  | 0     | 0      |
| 2021 | ÅSGARD B | Drilling                              | Drilling                                       | Not present                                              | 120.1 | 0     | 0      |
| 2021 | ÅSGARD B | Flare gas that does not burn          | Non-flammable flare gas                        | Not present                                              | 80.2  | 0     | 0      |
| 2021 | ÅSGARD B | Flare gas that does not burn          | Inert gas flushed open flare                   | Not present                                              | 80.3  | 0     | 0      |
| 2021 | ÅSGARD B | Gas analysers and test stations       | Gas analysers and test stations                | Not present                                              | 110.1 | 0     | 0      |
| 2021 | ÅSGARD B | Gas freeing of process systems        | Gas freeing of process systems                 | Not present                                              | 140.1 | 0     | 0      |
| 2021 | ÅSGARD B | General addition                      | FPSO                                           | Not present                                              | 900.1 | 0     | 0      |
| 2021 | ÅSGARD B | Storage tanks for crude oil at FPSOs  | Gas freeing in connection with tank inspection | Not present                                              | 130.1 | 0     | 0      |
| 2021 | ÅSGARD B | Storage tanks for crude oil at FPSOs  | Abnormal operating situation                   | Not present                                              | 130.2 | 0     | 0      |
| 2021 | ÅSGARD B | Leaks in the process                  | Larger gas leaks                               | Not present                                              | 90.1  | 0     | 0      |
| 2021 | ÅSGARD B | Monoethyleneglycol (MEG) regeneration | MEG degassing tank                             | Not present                                              | 20.1  | 0     | 0      |
| 2021 | ÅSGARD B | Monoethyleneglycol (MEG) regeneration | Stripping gas                                  | Not present                                              | 20.3  | 0     | 0      |

|      |          |                                      |                                               |             |       |   |   |
|------|----------|--------------------------------------|-----------------------------------------------|-------------|-------|---|---|
| 2021 | ÅSGARD B | Produced water handling              | Flotation gas                                 | Not present | 40.3  | 0 | 0 |
| 2021 | ÅSGARD B | Produced water handling              | Flotation tank / CFU                          | Not present | 40.2  | 0 | 0 |
| 2021 | ÅSGARD B | Produced water handling              | Produced water degassing tank                 | Recycled    | 40.1  | 0 | 0 |
| 2021 | ÅSGARD B | Centrifugal compressor sealant oil   | Degassing pots                                | Recycled    | 50.1  | 0 | 0 |
| 2021 | ÅSGARD B | Centrifugal compressor sealant oil   | Sealing oil storage tank                      | Not present | 50.3  | 0 | 0 |
| 2021 | ÅSGARD B | Purge and blanket gas                | Purge and blanket gas                         | Not present | 100.1 | 0 | 0 |
| 2021 | ÅSGARD B | Pistonne compressor                  | Separator chamber                             | Not present | 60.1  | 0 | 0 |
| 2021 | ÅSGARD B | Pistonne compressor                  | Crank shaft housing                           | Not present | 60.2  | 0 | 0 |
| 2021 | ÅSGARD B | Triethyleneglycol (TEG) regeneration | Stripping gas                                 | Recycled    | 10.3  | 0 | 0 |
| 2021 | ÅSGARD B | Triethyleneglycol (TEG) regeneration | TEG degassing tank                            | Recycled    | 10.1  | 0 | 0 |
| 2021 | ÅSGARD B | Dry compressor seals                 | Leakage of primary seal gas to secondary vent | Not present | 70.3  | 0 | 0 |
| 2021 | ÅSGARD B | Dry compressor seals                 | Secondary seal gas                            | Not present | 70.2  | 0 | 0 |

1990-2016 time series

The method for calculating the timeseries 1990-2016 for venting and diffuse emissions is as follows:

$$\text{Emissions per year} = \text{Oil and gas production (in Sm}^3 \text{ oil equivalents), totals sold per year} * \text{average emissions per oil equivalent 2017-2018}$$

We have considered different issues before choosing the mentioned method for recalculation for the timeseries:

- We checked if implied emission factors for gas and oil fields differed and found no relationship between implied emission factors and gas share of the total production for neither venting nor diffuse emissions, see Figure 3-19 and Figure 3-20. Regarding venting, the implied emission factor for most fields is lower than the IPCC (2006) tier I emission factors. See Figure 3-20. For diffuse emissions on the other hand, most fields have a higher implied emission factor than the IPCC tier I emission factor (Figure 3-20 (IPCC 2006)). For further comparisons between IPCC and Norwegian emission factors, see section 3.4.4.2.
- We checked whether scaling the reported emissions estimated with old method with new estimates with new methodology would be suitable. There were large changes in emissions when converting to new methodology for several installations and therefore we considered scaling of emissions not being usable
- The method now used to extrapolate emissions from 2017 back to 1990 does not take into account improvements in technology during the period. We have assumed same emissions per unit produced oil equivalent for the whole timeseries. In reality it is most probable that there have been technology improvements and if so, we might underestimate the emissions early in the timeseries. It is an open question if we should have adjusted the emissions the first years of the inventory but due to lack of available data we have not done so.

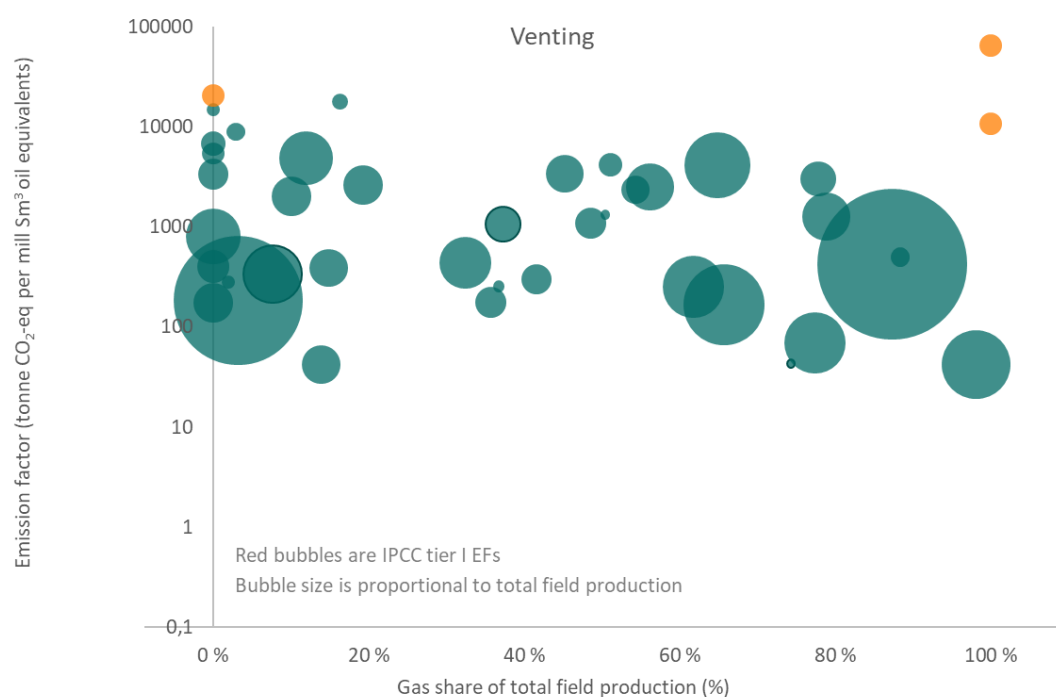


Figure 3-19: Relationship between emission factor for venting in tonne CO<sub>2</sub> equivalents (from CH<sub>4</sub> and NMVOC) per mill Sm<sup>3</sup> oil equivalents, and gas share of total field production (2021). Each bubble represents a gas/oil field, and the bubble size is proportional to the total field production. IPCC tier I emission factors (orange bubbles) are added as a reference. The bubble size of the IPCC factors corresponds to a field production of 1 mill Sm<sup>3</sup>. For further information see guidelines in Norwegian Oil and Gas (2021a).



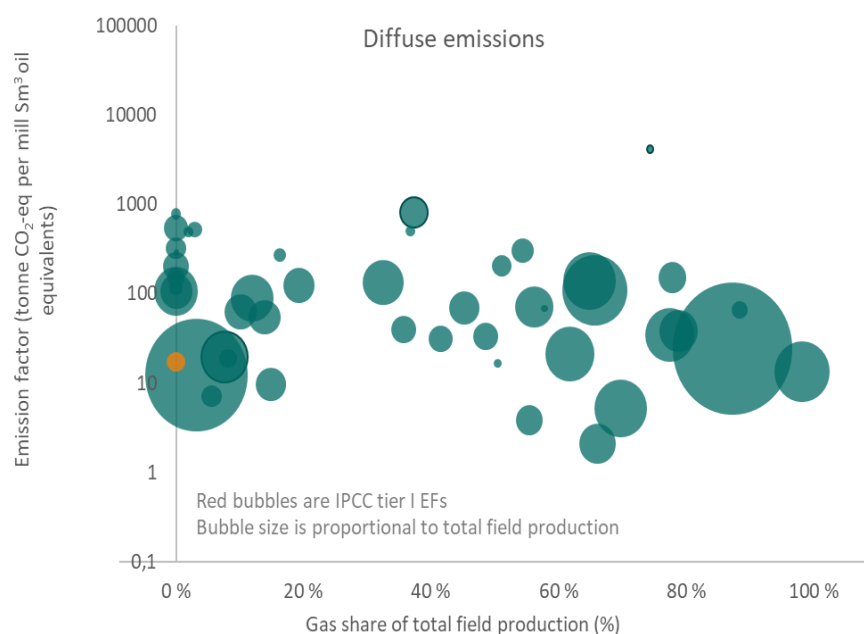


Figure 3-20. Relationship between emission factor for diffuse emissions in tonne CO<sub>2</sub> equivalents (from CH<sub>4</sub> and NMVOC) per mill Sm<sup>3</sup> oil equivalents, and gas share of total field production (2021). Each bubble represents a gas/oil field, and the bubble size is proportional to the total field production. The IPCC tier I emission factor (orange bubbles) is added as a reference. The bubble size of the IPCC factors corresponds to a field production of 1 mill Sm<sup>3</sup>. For further information see guidelines in Norwegian Oil and Gas (2021a).

#### 3.4.4.3 Activity data – Venting

Dedicated activity data are used by operators to estimate and report venting and diffuse emissions from the different emission sources. E.g., for the produced water degassing tank, AD will be accumulated quantity of produced water through the degassing point during the reporting period. For common vent, volume of natural gas and volume waste gas from source quantified by source quantification may be used. For drilling, thenumber of wellbores serves as AD. See guidelines in Norwegian Oil and Gas (2021a) and further elaboration in Husdal et al. (2016). Only emissions are reported by the operators.

#### 3.4.4.4 Emission factors – Venting

Dedicated emissions factors are used for estimating and reporting venting and diffuse emissions from individual sources, e.g. small gas leaks, drilling and produced water (grams methane and grams NMVOC per m<sup>3</sup> produced water through the degassing point and per bar pressure drop from nearest upstream degassing point), see guidelines in Norwegian Oil and Gas (2021a) and further elaboration in Husdal et al. (2016)

#### **3.4.4.1 Uncertainties and time-series consistency - Venting**

The uncertainty in CH<sub>4</sub> and NMVOC emissions from venting and diffuse emissions and, hence, in the indirect emissions of CO<sub>2</sub>, is much higher than for flaring.

All uncertainty estimates for this source are given in Annex II.

#### **3.4.4.2 Source-specific QA/QC and verification - Venting**

The requirements in the "Management Regulation" 34c (see above) text above refers to QC within the reporting company as well as QC by Offshore Norway (the employer and industry organization for companies with activities related with the Norwegian continental shelf.

The annually reports from the operators are quality checked by NEA. This includes for instance crosschecking of reported CO<sub>2</sub> emission data against ETS-reports and crosschecking of reported fugitive emissions (methane and NMVOC) against data reported in Footprint by the operators. Annual emissions from loading of crude oil onto shuttle tankers on the Norwegian continental shelf are reported by the VOC Industrial cooperation. The VOC Industrial cooperation reports is available in Norwegian.

We also evaluate historical trends by looking at excel-plots and figures generated from EEH. Results which deviate from previous reports are then easily identified and followed up against the operator. This might lead to corrections in Footprint.

In the auditing of the reported emissions, we have special focus on e.g., field specific methods, sources with high emission on the specific field and leakages.

A verification of the venting emissions against IPCC default factors was requested in the ARR 2020 review report. A comparison of reported nmVOC and CH<sub>4</sub> venting/diffuse emissions to estimates using IPCC default factors is shown in Figure 3-21. Gas processing is not included, as this mainly occur on onshore facilities reported in 1B2b6.

The comparison shows that emissions are low relative to the IPCC default factors. The CH<sub>4</sub> reported emissions are 5-10% of emission values using IPCC default factors. For nmVOC reported emissions are 10-23% of values found using IPCC default factors.

Information on the background for the low CH<sub>4</sub> emissions (technology, regulatory regimes, reporting regimes, etc.) may be found in section 3.4.4.1. Further information on the emission factors may be found in section 3.4.4.2 and in Figure 3-19 and Figure 3-20.

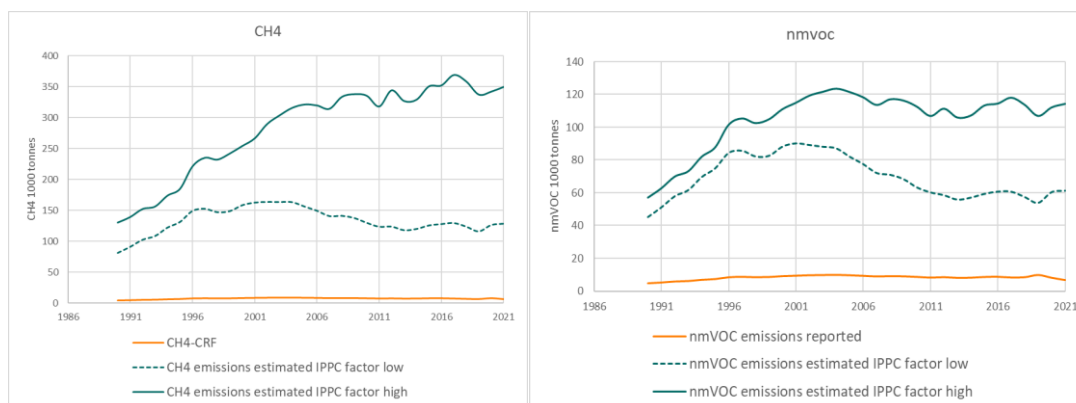


Figure 3-21. Emissions from venting and fugitive emissions as reported in the CRF and as estimated using IPCC default factors (min and max). Source: Statistics Norway/Norwegian Environment Agency

#### 3.4.4.3 Category-specific recalculations

**Reallocation:** Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

#### 3.4.4.4 Category-specific planned improvements - Venting

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 3.4.5 Fugitive Emissions from Flaring, 1.B.2.c Flaring (Key category for CO<sub>2</sub> and CH<sub>4</sub>)

#### 3.4.5.1 Description – Flaring

The sector *1.B.2.c Flaring* includes emissions from flaring of gas offshore during extraction and production, at gas terminals and at refineries. Emissions of CH<sub>4</sub>, CO<sub>2</sub> and N<sub>2</sub>O from flaring of oil when well-testing is reported in sector 1.B.2.c flaring.

Most of the emissions in sector *1.B.2.c Flaring* come from flaring of natural gas offshore (during well testing, extraction, production, and pipeline transport) and at gas terminals, and flaring of refinery gas at the refineries. There is some flaring of oil in connection with well testing – amounts flared, and emissions are reported to the Norwegian Petroleum Directorate and the Norwegian Environment Agency.

CH<sub>4</sub> and CO<sub>2</sub> from venting and flaring is according to Approach 1 and 2 *key category* with respect to both level and trend.

**The petroleum Act** states that flaring is prohibited unless for safety reasons. Permits are granted on a case-by-case basis on technical and safety grounds. This is a main reason why the flare gas volumes emitted from upstream oil and gas installations in Norway are less than 1/3 of the global average.

The *CO<sub>2</sub> Tax Act* introduced in 1991 is a tax on the burning of oil and gas in the offshore petroleum industry, giving rise to further reductions of flaring and cold venting.

Another instrument is the *Greenhouse Gas Emission Trading Act*.

Norway is a part of the harmonized EU ETS. Norway has implemented the EU ETS regulations.

### **3.4.5.2 Methodological issues - Flaring**

#### Flaring of gas offshore - CO<sub>2</sub>

The general method for calculating CO<sub>2</sub> emissions from flaring offshore is the amount of gas flared at each field multiplied by field specific emissions factors.

Gas specific data about the gas flared is not available for all flares and years. Therefore, the method used for calculating emissions for this source category is not exactly the same for all years.

#### Estimations of CO<sub>2</sub> 1990-2007.

For the period 1990-2007 the emissions are estimated from the amount of gas flared per field and emission factor based on EU ETS data for 2013. See information below in sub-chapter Emission factors about the emission factors that are used.

#### Estimations of CO<sub>2</sub> after 2007.

The EU ETS data are reported annually to the Norwegian Environment Agency. From 2008, emissions of CO<sub>2</sub> from flaring used in the inventory is estimated as follows:

- Reported EU ETS emissions from flares based on CMR data are used unchanged
- Fields where some flares are with, and some are without CMR data: An average EF for the field based on the CMR data for 2014 is calculated and used for the flares using default EF. For the first years with EU ETS this method is often used for the fields as a whole and thereafter up to 2014 to a lesser degree
- Gas fields with flaring but without any CMR data in 2014: The average emissions factor for 2014 of 2.694 CO<sub>2</sub> per Sm<sup>3</sup> based on all CMR data is used.

For the years after 2014, the same procedure is used for each new year, but the time series is not recalculated annually.

We consider that the method is consistent for all years.

#### 3.4.5.2.1 Estimations of CH<sub>4</sub> and N<sub>2</sub>O from flaring of gas offshore

Estimated emissions of CH<sub>4</sub> from flaring of gas offshore is calculated by Statistics Norway for 1990-2002 and is thereafter based on reported emission data from the field operators to the Norwegian Petroleum Directorate and the Norwegian Environment Agency. N<sub>2</sub>O emissions from flaring is estimated by Statistics Norway for all years.

#### Well testing

Emissions of CH<sub>4</sub> and N<sub>2</sub>O from flaring of *oil in well testing* is estimated for all years by Statistics Norway based on the amount of oil well tested reported annually by the field operators to the Norwegian Petroleum Directorate and the Norwegian Environment Agency. The same emission factors are used for the whole period. CO<sub>2</sub> emissions from well testing is based on the plants annual report.

#### Gas terminals

Emissions of CO<sub>2</sub> from flaring at the four *gas terminals* that is included in the inventory are reported from the plant.

#### Refineries

The *refineries* report annually CO<sub>2</sub> emissions from flaring to the Norwegian Environment Agency. The emissions are calculated by multiplying the amount of gas flared with plant specific emission factors. See additional information in section 3.2.1.

#### **3.4.5.3 Activity data - Flaring**

Amounts of gas flared at offshore oil and gas installations are reported monthly by the operators to the Norwegian Petroleum Directorate.

Amounts of gas flared at the four gas terminals are reported to the Norwegian Petroleum Directorate and the Norwegian Environment Agency.

Amounts of refinery gas flared are found by distributing the total amounts of refinery gas between different combustion technologies by using an old distribution key, based on data collected from the refineries in the early 1990s. This distribution is confirmed in 2003.

### 3.4.5.4 Emission factors - Flaring

#### 3.4.5.4.1 Flaring offshore – CO<sub>2</sub>

It is mandatory for oil and gas field operators included in the EU ETS to use field or flare specific emissions factor in the calculation of CO<sub>2</sub>. If no flare specific factor is used the default emissions factor is 3.73 kg CO<sub>2</sub> per Sm<sup>3</sup>. The default emission factor is often considerable higher than measured emission factors. This has motivated the field operators to establish flare and field specific emissions factors. So, since 2013, there are flare specific factors for most of the flares.

The field specific factors are estimated in a model developed by the Christian Michelsen Research (CMR) institute. The estimations are based on measurements with ultrasound of mass and volume on each flare.

There are several flares on a field but flare specific emission factors are not estimated for all flares. For each field it is estimated a field specific emission factor based on the flares with measurement data. For 2013, it is also calculated an average emissions factor of 2.637 kg CO<sub>2</sub> per Sm<sup>3</sup> for all flares at all fields with measurements data.

#### Emissions factors 1990-2007

An annual emission factor is estimated from the field specific CMR measurements from 2013 weighted with the amount of flared gas for each field. The amount of gas for 1990-99 are from the Norwegian Petroleum Directorate and from the Footprint database for 2000-2015.

#### Emissions factors after 2007

For the years after 2007 there is information in the EU ETS about each single flare. At most fields there are a mixture of flares with CMR emission factors and default factors.

The emission factors used for calculation of emissions after 2007 is explained in sub-chapter "*Estimations of CO<sub>2</sub> after 2007*" above.

Table 3.35 presents the average EF for flaring offshore for the period 1990-2021.

#### 3.4.5.4.2 Gas terminals

In Table 3.35, the CO<sub>2</sub> emission factors for flaring at one gas terminal are shown. The CO<sub>2</sub> emissions from flaring at that gas terminal were in 2021 28 000 tonnes.

#### 3.4.5.4.3 Well testing

Emission factors used in the calculations for well testing are shown in [Table 3.36](#). During the review of the 2008 inventory submission the expert review team raised question to that CH<sub>4</sub> and N<sub>2</sub>O from well testing offshore were not included in the inventory. Norway then estimated the emissions of CH<sub>4</sub> and N<sub>2</sub>O and presented the result for the expert review team. The emission estimates were for the first time included in the inventory in the 2010 submission.

**Table 3.35 Emission factors for flaring of natural gas at offshore oil fields and one gas terminal on shore. 1990-2021.**

|      | Average emission factor for flaring at one gas terminal | Average emission factor for flaring offshore    |
|------|---------------------------------------------------------|-------------------------------------------------|
|      | tonne CO <sub>2</sub> /tonne natural gas                | kg CO <sub>2</sub> /Sm <sup>3</sup> natural gas |
| 1990 | 2.7                                                     | 2.70                                            |
| 1991 | 2.7                                                     | 2.66                                            |
| 1992 | 2.7                                                     | 2.73                                            |
| 1993 | 2.7                                                     | 2.80                                            |
| 1994 | 2.7                                                     | 2.79                                            |
| 1995 | 2.7                                                     | 2.69                                            |
| 1996 | 2.7                                                     | 2.66                                            |
| 1997 | 2.7                                                     | 2.69                                            |
| 1998 | 2.7                                                     | 2.74                                            |
| 1999 | 2.7                                                     | 2.75                                            |
| 2000 | 2.7                                                     | 2.73                                            |
| 2001 | 2.7                                                     | 2.65                                            |
| 2002 | 2.7                                                     | 2.68                                            |
| 2003 | 2.7                                                     | 2.63                                            |
| 2004 | 2.7                                                     | 2.63                                            |
| 2005 | 2.7                                                     | 2.62                                            |
| 2006 | 2.69                                                    | 2.63                                            |
| 2007 | 2.67                                                    | 2.66                                            |
| 2008 | 2.67                                                    | 2.64                                            |
| 2009 | 2.67                                                    | 2.85                                            |
| 2010 | 2.65                                                    | 2.89                                            |
| 2011 | 2.76                                                    | 2.93                                            |
| 2012 | 2.75                                                    | 2.80                                            |
| 2013 | 2.62                                                    | 2.71                                            |
| 2014 | 2.59                                                    | 2.77                                            |
| 2015 | 2.53                                                    | 3.03                                            |
| 2016 | 2.59                                                    | 3.16                                            |
| 2017 | 2.54                                                    | 2.65                                            |
| 2018 | 2.65                                                    | 2.70                                            |
| 2019 | 2.65                                                    | 2.80                                            |
| 2020 | 2.63                                                    | 2.70                                            |
| 2021 | 2.72                                                    | 2.72                                            |

Source: Norwegian Environment Agency/Norwegian Petroleum Directorate/Statistics Norway



| <b>Table 3.36 Emission factors for flaring in connection with well testing.</b> |                              |                                                                |                                                |               |
|---------------------------------------------------------------------------------|------------------------------|----------------------------------------------------------------|------------------------------------------------|---------------|
| <b>Compounds (unit)</b>                                                         | <b>Unit/tonne flared oil</b> | <b>Source</b>                                                  | <b>unit/kSm<sup>3</sup> flared natural gas</b> | <b>Source</b> |
| <b>CO<sub>2</sub> (tonnes)</b>                                                  | 3.20                         | SFT (1990)                                                     | 2.34                                           | SFT (1990)    |
| <b>CO<sub>2</sub> (tonnes)</b>                                                  | 0.00041                      | Same factors as for fuel oil used for boilers in manufacturing | 0.00024                                        | (IPCC 1997)   |
| <b>N<sub>2</sub>O (tonnes)</b>                                                  | 0.000031                     |                                                                | 0.00002                                        | OLF (2009)    |
| <b>NM VOC (tonnes)</b>                                                          | 0.0033                       | OLF (2009) <sup>1</sup>                                        | 0.00006                                        | OLF (2009)    |
| <b>CO (tonnes)</b>                                                              | 0.018                        | OLF (2009) <sup>1</sup>                                        | 0.0015                                         | OLF (2009)    |

<sup>1</sup>The Norwegian Oil Industry Association

### 3.4.5.5 Uncertainties and time-series consistency - Flaring

The uncertainty in the amount of gas flared is in Rypdal and Zhang (2000) regarded as being low,  $\pm 1.4\%$ , due to that there is a tax on gas flared and there is requirement by law that the gas volume flared is measured (Norwegian Petroleum Directorate 2001). The uncertainty in the CO<sub>2</sub> emission factor for flaring is  $\pm 10$  (Rypdal & Zhang 2000).

The uncertainty in the amount of gas flared is in regarded as being low,  $\pm 1.4\%$ , based on data reported in the emission trading scheme (Norwegian Climate and Pollution Agency 2011) and assumptions in Rypdal and Zhang (2000). The uncertainty in the CO<sub>2</sub> emission factor for flaring is  $\pm 4.5$  (Norwegian Climate and Pollution Agency 2011) and Rypdal and Zhang (2000). All uncertainty estimates for this source are given in Annex II.

### 3.4.5.6 Source-specific QA/QC and verification - Flaring

Statistics Norway gathers activity data used in the calculation from the Norwegian Petroleum Directorate. The figures are quality controlled by comparing them with the figures reported in the field operators annually report to the Norwegian Environment Agency and the Norwegian Petroleum Directorate and time series are checked.

Statistics Norway and the Norwegian Environment Agency perform internal checks of the reported data for venting from the field operators. Some errors in the time-series are usually found and the field operators are contacted, and changes are made. The same procedure is followed to check the amount of gas reported as flared. The quality of the activity data is considered to be high due to a tax on gas flared offshore. The Norwegian Petroleum Directorate has a thorough control of the amount of gas reported as flared. The oil and gas sector is included in the EU ETS from 2008.

#### **3.4.5.7 Category-specific recalculations**

##### **1B2C2ii Gas**

- New emission data for CO<sub>2</sub> for 2018

#### **3.4.5.8 Category-specific planned improvements - Flaring**

No planned activities this year that will improve the data quality or the documentation for this source category.

## 3.5 CO<sub>2</sub> capture and storage at oil and gas production fields, 1C (Key Category for CO<sub>2</sub>)

### 3.5.1 Overview

This chapter describes emissions related to the capture, transport, and storage of CO<sub>2</sub> from natural gas produced at the gas-condensate field Sleipner Vest (including gas from the Gudrun field and the Utgard field) and the gas field Snøhvit (including Albatross).

Emissions occur primarily from venting of captured CO<sub>2</sub> when the injection facilities are not operating. Smaller emissions occur from a number of minor sources such as leakage from compressors. No emissions are reported from pipeline transport or from the CO<sub>2</sub> reservoirs.

The emissions are reported under 1C CO<sub>2</sub> *Transport and storage*. The emissions were until NIR 2016 reported in 1B2c together with indirect CO<sub>2</sub> emissions from CO<sub>2</sub> and NMVOC from venting and other fugitive emissions. The reporting in CRF table 1.C also includes data on total CO<sub>2</sub> capture and injected amounts.

### 3.5.2 CO<sub>2</sub> capture and storage at the oil and gas production field Sleipner Vest

#### 3.5.2.1 Description

The natural gas in the Sleipner Vest offshore gas-condensate field in the North Sea contains about 9% CO<sub>2</sub>. The CO<sub>2</sub> content must be reduced to about 2.5% to meet sales gas specifications. The CO<sub>2</sub> removed has decreased sharply over the last years two years due to depletion of the reservoir.

When Sleipner Vest was planned around 1990 the considerations were influenced by the discussions about strategies to reduce greenhouse gas emissions and a possible national tax on CO<sub>2</sub> emissions (introduced in 1991 and extended in 1996). It was therefore decided that the removed CO<sub>2</sub> should be injected for permanent storage into a geological reservoir. The selection of an appropriate reservoir is essential for the success of geological storage of CO<sub>2</sub>. In the search for a suitable reservoir the operators were looking for a saline aquifer with reasonable high porosity and a cap rock above to prevent leakage. Furthermore, the CO<sub>2</sub> should be stored under high pressure – preferably more than 800 meters below the surface. Under these conditions CO<sub>2</sub> is buoyant and less likely to move upwards than CO<sub>2</sub> in gaseous form.

The Utsira Formation aquifer, which is located above the producing reservoirs at a depth of 800 – 1000 meters below sea level, was chosen for CO<sub>2</sub> storage because of its shallow depth, its large extension (which guarantees sufficient volume), and its excellent porosity and permeability (which is well suited for high injectivity). The formation is overlain by a thick, widespread sequence of Hordaland Group shales, which should act as an effective barrier to vertical CO<sub>2</sub> leakage, see Figure 3-22.

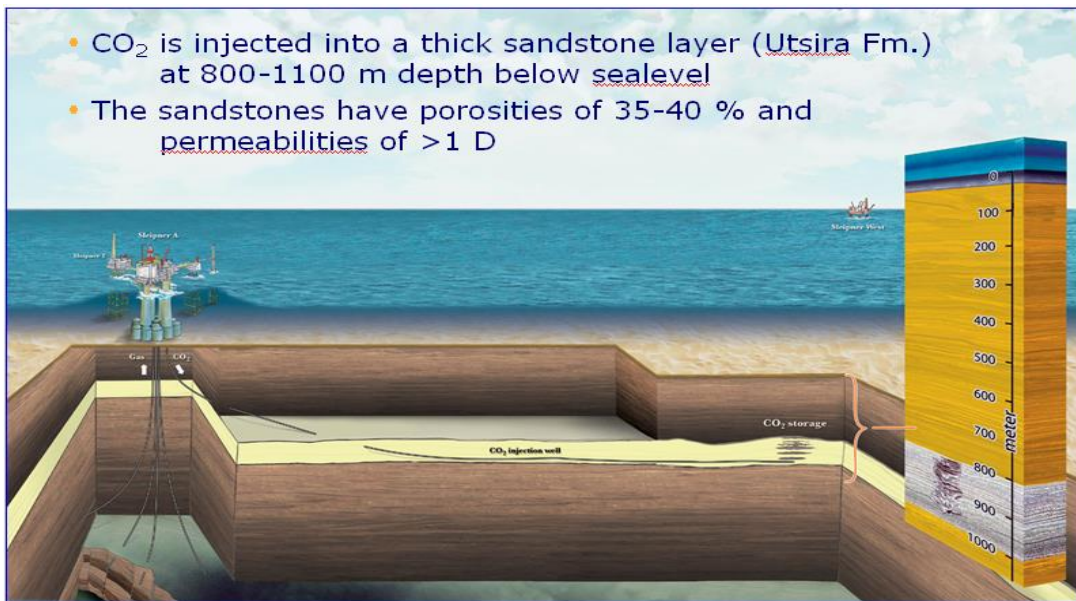


Figure 3-22. CO<sub>2</sub> capture from Sleipner Vest well stream and storage at Sleipner.  
Source: Equinor (Statoil)

The reservoir was characterised by reservoir information such as seismic surveys and information from core drillings.

In the Sleipner case it was very important to locate the injection well and the storage site such that the injected CO<sub>2</sub> could not migrate back to the Sleipner A platform (SLA) and the production wells. This will both prevent corrosion problems in the production wells and minimise the risk of CO<sub>2</sub> leakage through production wells. The injection point is located 2.5 km east of the Sleipner A platform. Migration evaluations have been based on the Top Utsira map (see figure AIV.2 in Annex IV) with the CO<sub>2</sub> expected to migrate vertically to the sealing shales and horizontally along the saddle point of the structure. This will take the CO<sub>2</sub> away from other wells drilled from the Sleipner platform. A more detailed description of the reservoir's suitability for long term CO<sub>2</sub> storage is given in Annex IV.

The field and the injection program have been in operation since 1996. The operator monitors the injected CO<sub>2</sub> with respect to leakages by 4 D seismic surveys.

Investigations carried out so far show that the injected CO<sub>2</sub> is kept in place without leaking out. In case unexpected CO<sub>2</sub> movements take place beyond the capture rock in the future it can be registered by the monitoring techniques. [Table 3.37](#) gives the amount of CO<sub>2</sub> injected since the project started in 1996.

**Table 3.37 CO<sub>2</sub> from the Sleipner field injected in the Utsira formation.**

| Year | CO <sub>2</sub> (ktonnes) | Year | CO <sub>2</sub> (ktonnes) | Year | CO <sub>2</sub> (ktonnes) |
|------|---------------------------|------|---------------------------|------|---------------------------|
| 1996 | 70                        | 2005 | 858                       | 2014 | 658                       |
| 1997 | 665                       | 2006 | 820                       | 2015 | 707                       |
| 1998 | 842                       | 2007 | 921                       | 2016 | 632                       |
| 1999 | 971                       | 2008 | 814                       | 2017 | 557                       |
| 2000 | 933                       | 2009 | 860                       | 2018 | 509                       |
| 2001 | 1 009                     | 2010 | 743                       | 2019 | 482                       |
| 2002 | 955                       | 2011 | 929                       | 2020 | 506                       |
| 2003 | 914                       | 2012 | 842                       | 2021 | 322                       |
| 2004 | 750                       | 2013 | 702                       | 2022 | 115                       |

Source: Source: Equinor (Statoil) / the Norwegian Environment Agency

When the injection is stopped due to maintenance or any unplanned reasons, the captured CO<sub>2</sub> is vented to the atmosphere. The amount of CO<sub>2</sub> vented to the atmosphere is included in the greenhouse gas inventory reported under 1C1a. The emissions from venting are presented in [Table 3.38](#).

**Table 3.38 Emissions of CO<sub>2</sub> vented from the Sleipner Vest CO<sub>2</sub> -injection plant due to inaccessibility of the injection facility.**

| Year | CO <sub>2</sub> (ktonnes) | Year | CO <sub>2</sub> (ktonnes) | Year | CO <sub>2</sub> (ktonnes) |
|------|---------------------------|------|---------------------------|------|---------------------------|
| 1996 | 81.0                      | 2005 | 6.2                       | 2014 | 5.4                       |
| 1997 | 29.0                      | 2006 | 2.5                       | 2015 | 0.8                       |
| 1998 | 4.2                       | 2007 | 6.4                       | 2016 | 4.6                       |
| 1999 | 9.1                       | 2008 | 13.6                      | 2017 | 0.8                       |
| 2000 | 8.3                       | 2009 | 4.6                       | 2018 | 1,6                       |
| 2001 | 3.1                       | 2010 | 0.9                       | 2019 | 0,1                       |
| 2002 | 87.6                      | 2011 | 2.4                       | 2020 | 1,2                       |
| 2003 | 23.9                      | 2012 | 5.9                       | 2021 | 2,1                       |
| 2004 | 21.4                      | 2013 | 5.0                       | 2022 | 0,3                       |

Source: The Norwegian Environment Agency

By 31.12.2022, 19 million tonnes CO<sub>2</sub> have been injected and stored in the Utsira Formation and 0.25 million tonnes CO<sub>2</sub> have been vented. Figure 3-23 shows the yearly injected and vented volumes for the entire injection period on Sleipner.

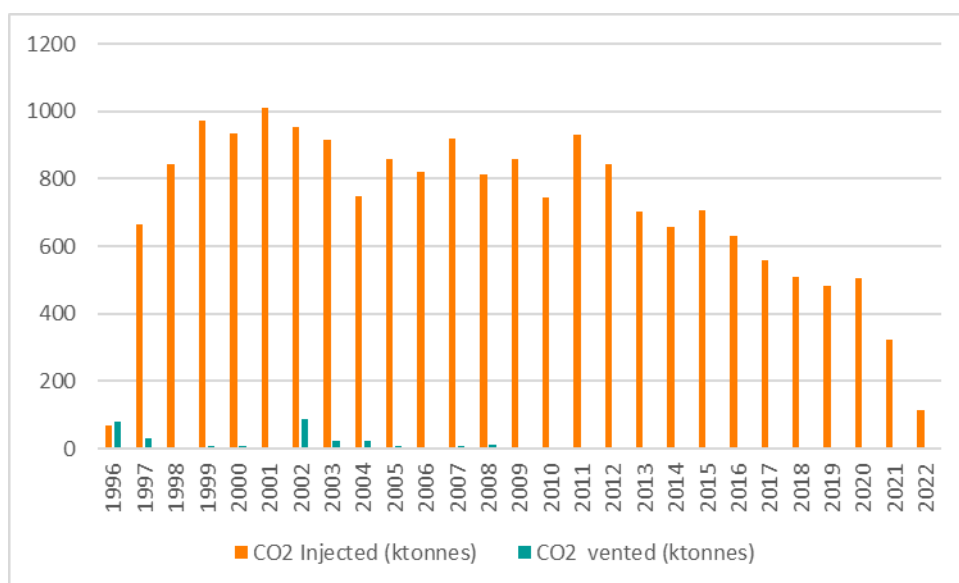


Figure 3-23 Injected and vented CO<sub>2</sub> at Sleipner Vest. Source: Norwegian Environment Agency

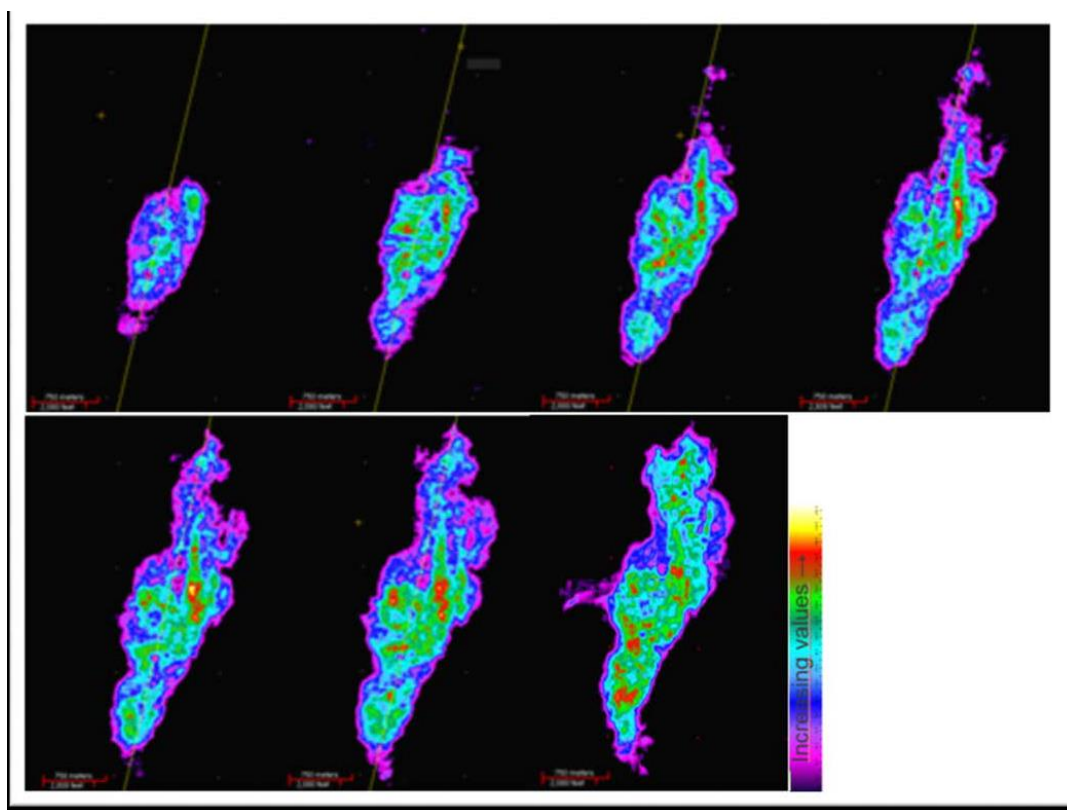
Diffuse emissions from the CO<sub>2</sub> capture plant (amine absorber) and the CO<sub>2</sub> compressor are estimated to about 1,0 kt CO<sub>2</sub>/year and these figures are included in CRF table 1.C. The compressorized CO<sub>2</sub> is transported by pipeline to the well head (injection well). The transport distance is 350 m and is controlled by pressure monitoring.

### 3.5.2.2 Methodological issues

The reported data covers emissions to the atmosphere when the injection system is out of operation. These emissions are determined by continuous metering of the gas stream by VCONE-meter. The reported amounts of CO<sub>2</sub> injected in the Utsira formation are based on continuous metering of the gas stream by orifice meter. The composition of the CO<sub>2</sub> stream is stable, about 98% CO<sub>2</sub> and the remaining 2% mainly methane and heavier hydrocarbons.

The diffuse emissions are estimated based on equipment specific leakage factors. CO<sub>2</sub> detectors are monitoring almost all potential leakages sources (e.g., flanges).

The Sleipner CO<sub>2</sub> injection project is considered to be the first industrial-scale, environmentally driven CO<sub>2</sub> injection project in the world. To document what happens with the CO<sub>2</sub> a European research project initially called SACS ("The saline aquifer carbon dioxide storage project") was organized around it. The SACS project ended in 2002 and was succeeded by the EU-co-funded CO<sub>2</sub>STORE and ECO<sub>2</sub>. The projects have run parallel to the development of Sleipner Vest and have special focus on monitoring and simulation. Research institutes and energy companies from several countries have participated in the projects. The core of the projects has been to arrive at a reasoned view of whether carbon dioxide remains in the Utsira sand and whether developments in this formation can be monitored. The migration of carbon dioxide through the aquifer is recorded by seismic surveys. Base line 3D seismic data were acquired in 1994, prior to injection, and the first repeat survey was acquired in 1999, when some 2.28 mill tonnes of CO<sub>2</sub> had been injected into the reservoir. This was followed by 4-D seismic surveys in 2001, 2002, 2004, 2006, 2008, 2010, 2013, 2016 and 2020. Data from the last survey will be presented in next year's report. The monitoring methodology and the results of the monitoring are described in Annex IV written by the operator Equinor (formerly called Statoil).



*Figure 3-24 Results of seismic monitoring Sleipner Vest, 1998-2016. Accumulated amplitudes on the differences between 1994 and respectively 2001, 2004, 2006, 2008, 2010, 2013 and 2016.*

*Source: Equinor (Statoil)*

The stored CO<sub>2</sub> has been monitored using time lapse seismic to confirm its behaviour and evaluate

- whether any of it has leaked into the overburden seal, the ocean, or the atmosphere, or
- whether any of it has migrated towards the Sleipner installations, potentially leading to corrosion problems for well casing

The results show that neither of these eventualities has occurred. is no sign of CO<sub>2</sub> above the top of Utsira Formation.

Results from the projects are published in several reports and articles such as:

- EU (2002)
- Arts et al. (2005)
- Chadwick et al. (2004)
- Chadwick et al. (2005)

A more detailed list of publications and presentations is given in Annex IV. The project has confirmed that sound waves reflect differently from carbon dioxide and salt water.

Comparing seismic data collected before and after injection started has allowed researchers to show how CO<sub>2</sub> deep inside the Utsira formation migrates (see figure AIV.5 in Annex IV). It is held under the layer of shale cap rock, 80 metres thick, which covers the whole formation. This extends for several hundred kilometres in length and about 150 kilometres in width.

The time-lapse seismic data clearly image the CO<sub>2</sub> within the reservoir, both as high amplitude reflections and as a pronounced velocity pushdown (see Figure 3-24 and figure AIV.4 in Annex IV).

The data also resolve a vertical CO<sub>2</sub> chimney, which is regarded the primary feeder of CO<sub>2</sub> in the upper part of the bubble.

Flow simulation models, which match the 4D seismic data reasonably well, have been used to predict the CO<sub>2</sub> behaviour, see Figure 3-25.



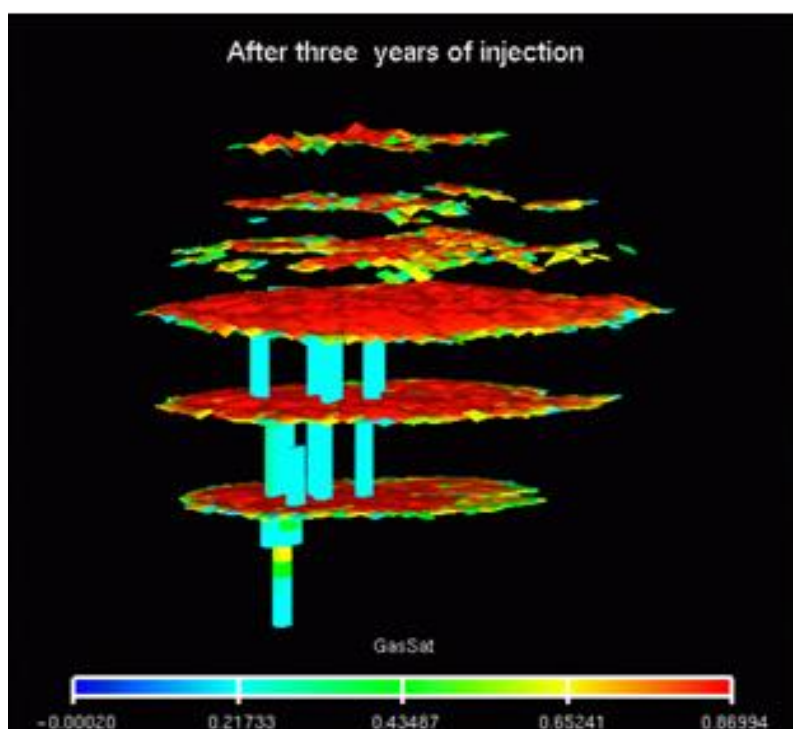


Figure 3-25. Flow simulation of CO<sub>2</sub> Sleipner Vest. Source: Equinor (Statoil)

The results from the simulations indicate that the cap rock shales provide a capillary seal for the CO<sub>2</sub> phase.

There is no seismic indication of faults within the upper part of the reservoir, and no indications of leakage into the capture rock.

The time-lapse seismic images clearly show the development of the CO<sub>2</sub> plume and have been used to calculate the amount of CO<sub>2</sub> in the reservoir. The volume calculated from the observed reflectivity and velocity pushdown is consistent with the injected volume.

Other monitoring conducted by Equinor are monitoring of the injected CO<sub>2</sub>, gravimetric monitoring, pressure measurements and well monitoring. For more details see Annex IV.

### 3.5.2.3 Uncertainties

The reported data covers emissions to the atmosphere when the injection system is out of operation. The accuracy in these measurements made by VCONE-meter is +/- 5%. The orifice meter used to meter the amount of CO<sub>2</sub> injected in the Utsira formation have +/- 3% accuracy. So far there has not been detected any leakage from the storage.

#### **3.5.2.4 Category-specific QA/QC and verification**

The results are promising, and the injected gas remains in place. Storage of CO<sub>2</sub> is regulated by the Pollution Control Act and the specific regulations of geological storage of CO<sub>2</sub> (entered into force January 1, 2016). Pursuant to the Pollution Control Act and the specific regulations, the operator shall hold a permit. According to the permit conditions Equinor shall monitor the CO<sub>2</sub> storage. Equinor reports annually the amount of CO<sub>2</sub> injected and emitted to The Norwegian Environment Agency. The injected CO<sub>2</sub> is so far proven to be removed from the atmosphere and hence, it is not reported as emissions in the emission inventory. When the injection of CO<sub>2</sub> is stopped for maintenance purposes, the operator pays a CO<sub>2</sub> tax for the emissions. From 2013 these emissions are included in the EU-ETS. In the national emissions inventory, the amount of CO<sub>2</sub> vented is reported under 1C2a - Injection.

#### **3.5.2.5 Category-specific recalculations**

There have been no recalculations performed for this source category this year. The formerly reported volumes for the years 2017 – 2021 was too high due to a defective flowmeter, and the corrected volumes is given in table 3.11 and figure 3.12.

#### **3.5.2.6 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **3.5.3 CO<sub>2</sub> capture and storage at Hammerfest LNG/the gas-condensate production field Snøhvit**

#### **3.5.3.1 Description**

The natural gas in the Snøhvit gas-condensate subsea field, including Albatross, in the Barents Sea contains about 5-7.5% CO<sub>2</sub>. Prior to the LNG production the CO<sub>2</sub> must be removed to avoid it freezing out in the downstream liquefaction process. The facilities for separation and injection of CO<sub>2</sub> are placed onshore at the Hammerfest LNG process plant at Melkøya.

An amine absorption unit performs the separation. The recovered CO<sub>2</sub> is condensed and recompressed before transported by a subsea pipeline and re-injected into Tubåen (until 2011) and Stø reservoir. A schematic of the CO<sub>2</sub> re-injection system is shown in Figure 3-26. About 0.8 Mtonnes CO<sub>2</sub> are removed from the feed gas every year at full production. During the expected lifetime of the field, about 23 million tonnes CO<sub>2</sub> from the feed gas will be removed and re-injected.

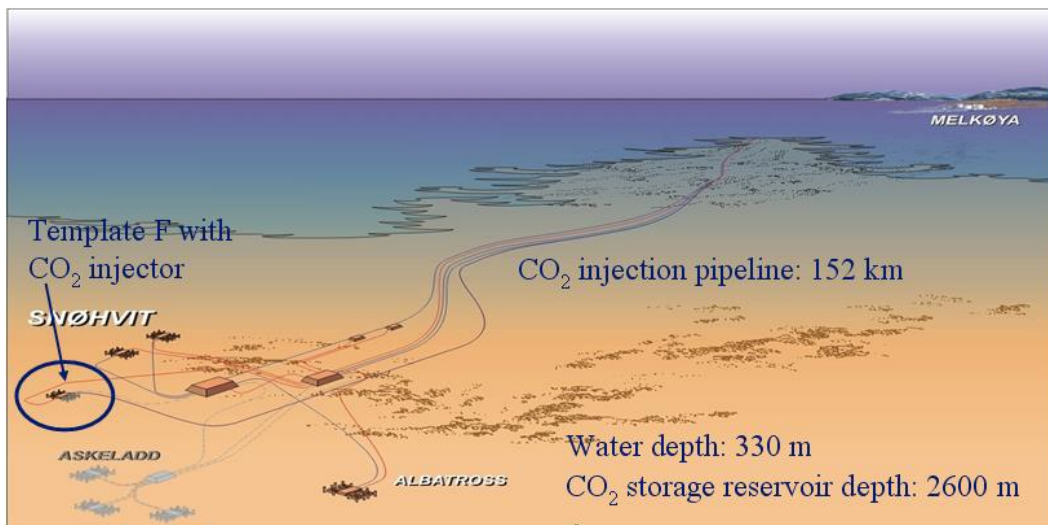


Figure 3-26. Snøhvit Field overview. Source: Equinor

### Reservoir

Several geological structures in the Snøhvit area were evaluated for disposal of CO<sub>2</sub>. Among four structures identified as possible candidates for CO<sub>2</sub> storage the water bearing Tubåen Formation on the Snøhvit and Albatross fields was chosen as the primary storage location.

Hammerfest LNG (former Snøhvit LNG Statoil) was in 2004 granted a permit pursuant to the Pollution Control Act to inject 730 000 tonnes of CO<sub>2</sub> per year into the geological formation, Tubåen. The permit was issued by the Norwegian Environment Agency. The LNG production and the CO<sub>2</sub> injection started in 2008. In 2018, the allowed amount was increased to 830 000 tonnes of CO<sub>2</sub> per year. The permit conditions were updated in line with requirements in the new CO<sub>2</sub> storage regulations adopted in 2016. In March 2011, the injection point was moved from Tubåen to the Stø reservoir, due to lower injectivity in Tubåen than expected.

The Snøhvit Field is not very complex structurally. Two well-defined fault directions, E-W and N-S, define most of the major structures. Minor internal faulting is present within the major structures.

Tubåen formation is a saline aquifer lying around 100-200 metres below the gas cap at Snøhvit. The formation has a thickness between 45 and 75 metres. Core samples show that the formation consists of relatively pure quartz sand. The porosity and permeability are 10-

16% and 200-800 md, respectively. The formation is bounded by large faults on all sides. Formation depth is 2600 m below sea level.

Stø water zone formation, which is the bottom of the current producing gas reservoir, was perforated for injection. The water zone has a thickness of 42 metres. Core samples show that the formation consists of relatively sand. The porosity and permeability are 15% and 400md, respectively (Table 3.39). Formation depth is 2450 m below sea level.

The geophysical, geological and petrophysical evaluations are based on 19 exploration wells and 10 development wells within the area. The data available from these wells are generally of good quality, including logs, core data and pressure data.

The reservoir was characterised by reservoir information such as seismic surveys and information from core drilling.

**Table 3.39 Key parameters for injection well F-2 H and Tubåen reservoir at the Snøhvit field. Stø reservoir pressure is being depleted by field production.**

| Key Parameters               | Tubåen     | Stø     |
|------------------------------|------------|---------|
| Initial reservoir pressure   | 288 bar    | 255 bar |
| Initial temperature          | 98 C       | 98 C    |
| Porosity                     | 10-16%     | 15%     |
| Permeability                 | 200-800 md | 400 md  |
| Reservoir depth              | 2600 m     | 2450 m  |
| Water depth at F-template    | 330m       | 330m    |
| Length pipeline from Melkøya | 152km      | 152km   |

#### Location of the CO<sub>2</sub> injection well F-2 H.

The CO<sub>2</sub> injection well is located at the F-segment at the western part of the Snøhvit reservoir (Figure 3-27). The injection pipeline is 152 km long (Figure 3-26). A new injection well, located in the G-segment, has been established in 2016.

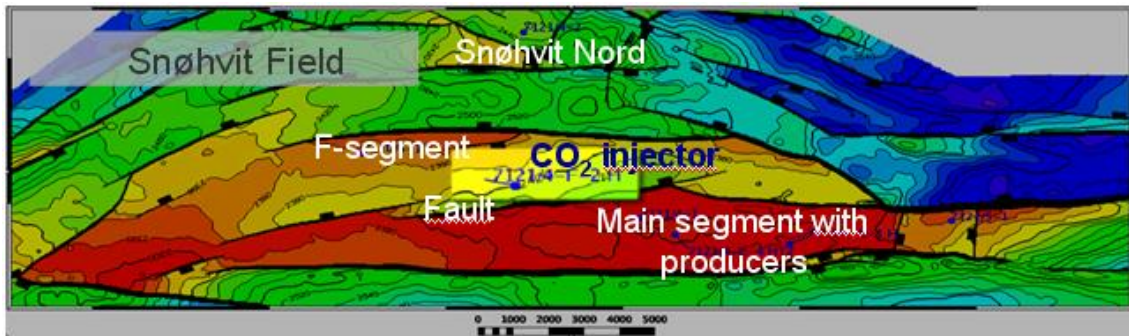


Figure 3-27. Location of the CO<sub>2</sub> well at the Snøhvit field. Source: Equinor (Statoil)

At the beginning, to keep the CO<sub>2</sub> as deep as possible, it was decided to perforate the mid and lower part of Tubåen as shown in Figure 3-28. Since injection was changed to Stø, additional perforations were done in the bottom of Stø as shown in Figure 3-28.

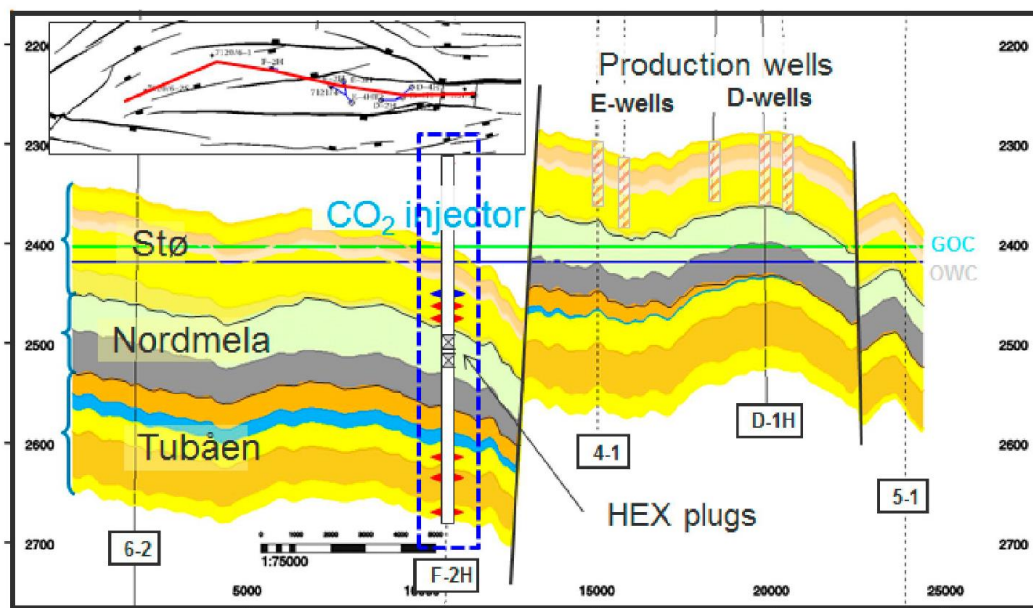


Figure 3-28. Cross-section of F-segment where CO<sub>2</sub> is injected, Snøhvit field formation. Source: Equinor

CO<sub>2</sub> injected and vented

By 31.12.2022, 1 087 ktonnes CO<sub>2</sub> have been injected into the Tubåen Formation, 6240 ktonnes have been injected into the Stø Formation, and 592 ktonnes CO<sub>2</sub> have been vented (Table 3.40). CO<sub>2</sub> venting occurs when the CO<sub>2</sub> reinjection system must shut down. The maximum vent rate is almost equal to the CO<sub>2</sub> removal flow rate. A separate vent stack for the CO<sub>2</sub> is provided at the plant.

**Table 3.40 Injected and vented CO<sub>2</sub> Hammerfest LNG/Snøhvit field.**

| Year | CO <sub>2</sub> injected (ktonnes) | CO <sub>2</sub> vented (ktonnes) | Year | CO <sub>2</sub> injected (ktonnes) | CO <sub>2</sub> vented (ktonnes) |
|------|------------------------------------|----------------------------------|------|------------------------------------|----------------------------------|
| 2007 | 0                                  | 71                               | 2015 | 679                                | 39                               |
| 2008 | 197                                | 93                               | 2016 | 750                                | 4                                |
| 2009 | 308                                | 50                               | 2017 | 680                                | 4                                |
| 2010 | 460                                | 93                               | 2018 | 758                                | 11                               |
| 2011 | 403                                | 87                               | 2019 | 721                                | 9                                |
| 2012 | 490                                | 55                               | 2020 | 422                                | 1                                |
| 2013 | 469                                | 27                               | 2021 | 0                                  | 0                                |
| 2014 | 587                                | 37                               | 2022 | 402                                | 11                               |

The following figure shows the yearly injected volumes in the Tubåen/Stø formation at the Snøhvit field and vented volumes for at Hammerfest LNG. These figures are reported to the Norwegian Environment Agency on a yearly basis.

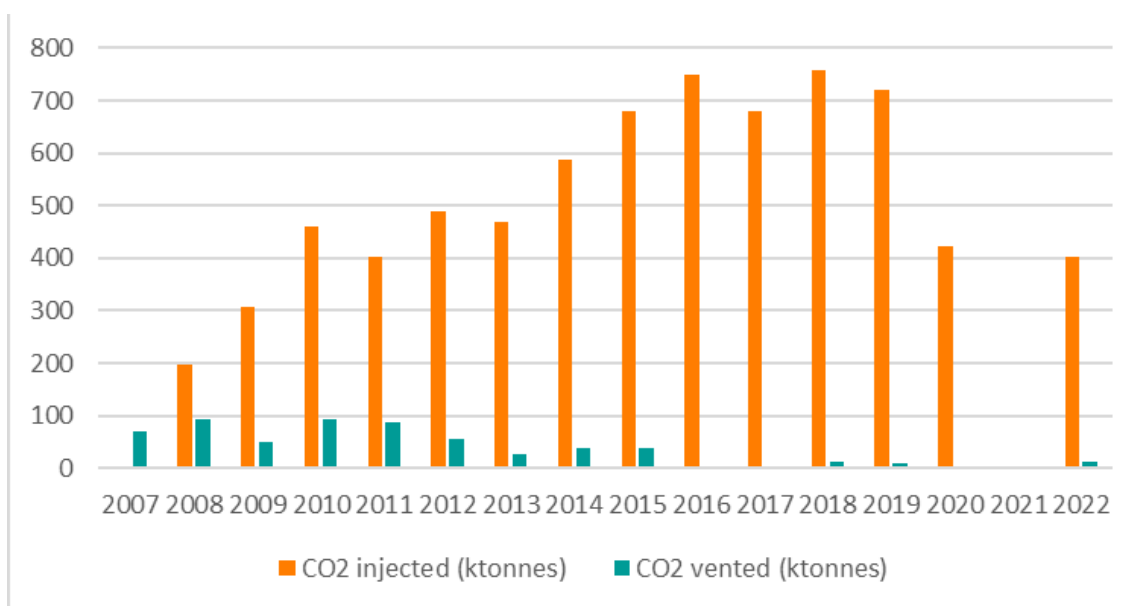


Figure 3-29. Injected and vented CO<sub>2</sub> at the Snøhvit field and Hammerfest LNG. Source: Statoil

In Sept. 2020 a fire at Hammerfest LNG caused damage to the air intake on one of the LNG plant's five power turbines. The production (and CO<sub>2</sub> injection) was shut down for repair until May 2022. Thus, no CO<sub>2</sub> was injected in this period.

### 3.5.3.2 Methodological issues

#### CO<sub>2</sub> injection well specification

The completion design basis for the CO<sub>2</sub> injector at Tubåen/Stø depth is a perforated 7" liner. A downhole pressure and temperature gauge is installed.

#### CO<sub>2</sub> re-injection system

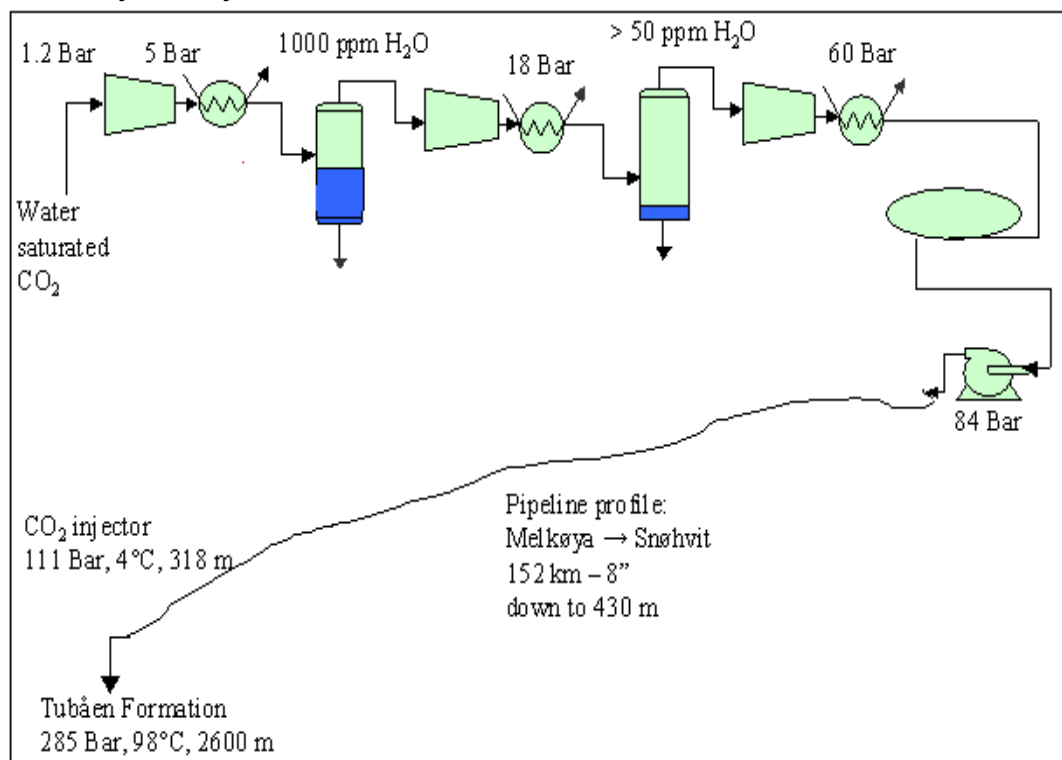


Figure 3-30. Schematic of the CO<sub>2</sub> injection system in the Snøhvit area. Source: Equinor

CO<sub>2</sub> is most likely re-injected as a single phase (liquid condition in the pipeline from the export pump to the well head, transformed to supercritical condition in the reservoir where the temperature is higher).

#### CO<sub>2</sub> venting to atmosphere

The reported data covers CO<sub>2</sub> emissions to the atmosphere when the injection system is out of operation. These emissions are measured by a venturi flow meter.

Flow metering of the well stream to the CO<sub>2</sub> injector is measured by an orifice meter.

Gas composition of injected or vented gas from the CO<sub>2</sub> injector is controlled by analyses. This is primarily done as a quality assurance of the CO<sub>2</sub> removal system. Analyses have shown that composition is 99.549% CO<sub>2</sub>, 0.0066% H<sub>2</sub>S, 0.331% CO<sub>2</sub> and 0.088% NMVOC (by weight). It has been agreed that in the reports to the environmental authorities, ventilated gas shall be reported as 100% CO<sub>2</sub>.

#### Diffuse sources and pipeline transport

Diffuse emissions from the CO<sub>2</sub> capture plant are estimated to about 1,0 kt CO<sub>2</sub>/year and these figures are included in CRF table 1.C.

For pipeline transport of CO<sub>2</sub>, emissions are reported as Not Estimated. The IPCC tier 1 method gives a medium emission factor of 0.0014 Gg per year and per km of transmission pipeline (IPCC (2006), vol 2, table 5.2). The pipeline is 152 km long, corresponding to an emission estimate of 0.2 kt CO<sub>2</sub>. However, based on our best knowledge we anticipate that this would overestimate emissions from the pipeline.

Firstly, the main sources of emissions are likely to be equipment at the ends of the pipeline. In the Snøhvit case, emissions from equipment at the input end is included with reported emissions from the Hammerfest plant.

Secondly, the pipeline and injection well are continuously monitored by pressure monitoring (downhole well, choke, export pump). The pipeline and injection well are also subject to acoustic deep-water survey and visual inspection by Remote Operated Vehicle to detect any sign of corrosion or irregularities which may cause leakages.

#### Reservoir monitoring by seismic

2D and 3D seismic surveys are carried out on a regular basis. Based on 3D seismic data 4D seismic is used to monitor CO<sub>2</sub> movement in vertical and horizontal direction, detect leakages or unexpected migration of CO<sub>2</sub> in the geological formation.

4D seismic monitoring was carried out in 2011, 2012, 2014, 2019 and 2022 to monitor the CO<sub>2</sub> plume migration inside the Stø formation and its movement towards the gas zone. Strong focus has also been on optimizing the reservoir simulation model in order to match the 4D observation. Reservoir simulation model is the main tool for predicting CO<sub>2</sub> flow in the future.

The strong 4D signal is mainly related to the fluid replacement effect, CO<sub>2</sub> replacing water. Some of the 4D signal close to the injector is also most likely related to thermal fracturing



because of cold CO<sub>2</sub> injection. The CO<sub>2</sub> follows the Stø2 layer and does not seem to migrate up into Stø3 due to the much lower permeability in Stø3 compared to Stø2.

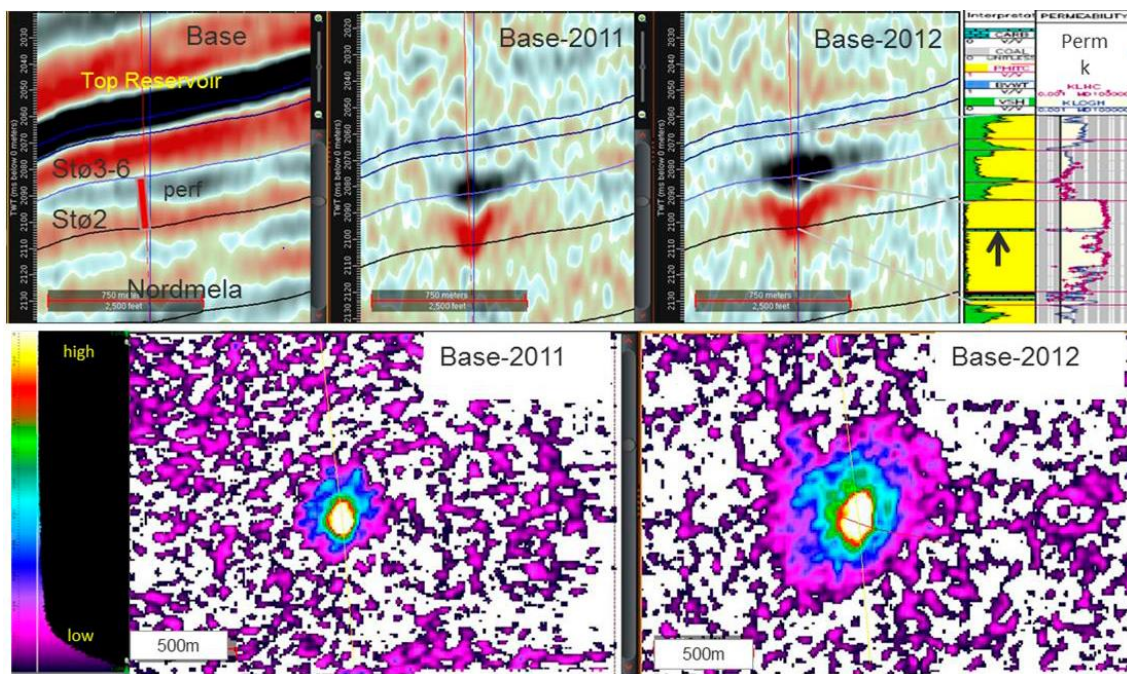
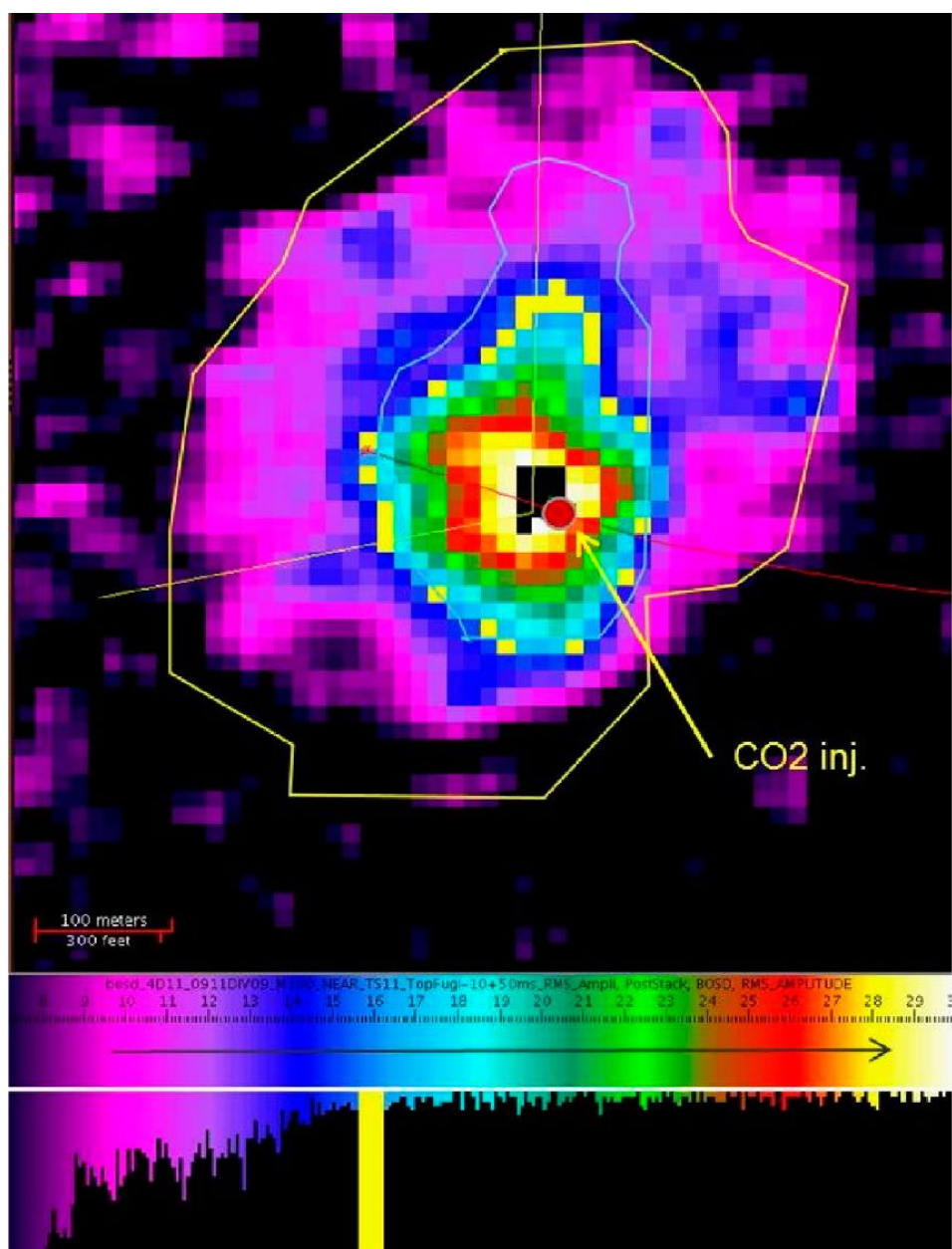


Figure 3-31 The upper figures show the differences from 2009 to 2012. The lower figures show 4D amplitude maps on CO<sub>2</sub> plume for 2009-2011 (left) and 2009-2012 (right). Source: Equinor (Statoil)



*Figure 3-32. Seismic 4D amplitude map from 2011, showing a clear anomaly around the CO<sub>2</sub> injector Pressure/temperature gauge, reservoir modeling and prediction of reservoir performance in Tubåen.*

The pressure development in the injection well is monitored daily by using data from the pressure and temperature (PT) gauge installed in the well. Due to problems during drilling, there is diameter restriction in the well and the PT gauge had to be installed about 600 m

above the reservoir. Actual bottom hole pressure is estimated based on gauge measurements and CO<sub>2</sub> PVT (pressure, volume, temperature). An Eclipse 300 Compositional simulation model is used for prediction pressure development in the well. In this model CO<sub>2</sub> is injected into the water filled Stø reservoir. Using this model, it has proven to be easy to match the CO<sub>2</sub> plume size/shape geometry in this model with time-lapses seismic data. A weakness of the model is that it does not include temperature and other advanced simulation physical effects. Temperature effects are likely in the near well area as CO<sub>2</sub> at 21 °C is injected into a reservoir of initially 91 °C.

Since mid-2011 CO<sub>2</sub> in liquid phase has been injected to Stø water saturated formation. The well has shown that its ability to receive injected CO<sub>2</sub> is stable. This is confirmed by weekly monitoring.

As can be seen from Figure 3-33, the reservoir pressure (green line) has depleted since May 2011 until December 2014. This is due to production of the gas zone above the water zone, from the gas zone.

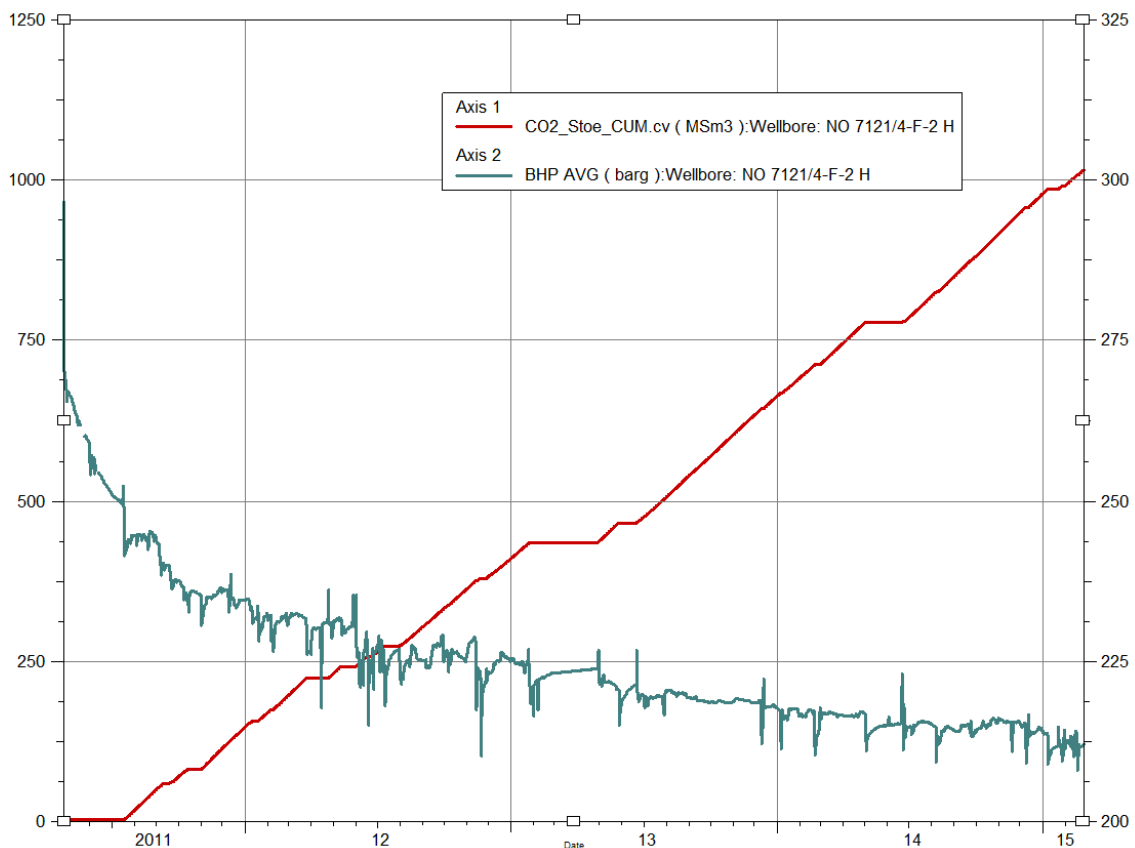


Figure 3-33. History pressures and volume injection into Stø formation. Source: Equinor

#### Gravimetric monitoring

A baseline gravity and seafloor subsidence monitoring survey was carried out over the Snøhvit and Albatross fields in June 2007. The closest benchmark is 419 m from the CO<sub>2</sub> injection well. A total of 76 sea floor benchmarks were deployed at the start of the survey, and relative gravity and depth was measured. A new gravity monitoring was carried out in spring 2011. Comparison of 2011 and 2007 gravity measurements confirmed the prognoses.

#### **3.5.3.3 Category-specific QA/QC and verification**

Operators for CO<sub>2</sub> storage projects must apply for a permit pursuant to the Pollution Control Act. In accordance with the permit provisions, Equinor has implemented system for monitoring the CO<sub>2</sub> storage. So far there is no sign of emissions to the water column or the atmosphere from the injected CO<sub>2</sub>. Hence the CO<sub>2</sub> injected is not reported as emissions in the emission inventory. Statoil pays a CO<sub>2</sub> tax for the emissions when the injection facility is out of operation due to maintenance etc. From 01.01.2013, these emissions are also regulated under the emission trade scheme (EU-ETS). The emissions of CO<sub>2</sub> and the

amounts of CO<sub>2</sub> injected are reported to the Norwegian Environment Authority. In the emissions inventory the amount of CO<sub>2</sub> vented at Hammerfest LNG (Snøhvit CO<sub>2</sub> storage project) – is reported under 1C2a - Injection 1B2c.

Equinor performs internal QA/QC for the ongoing CO<sub>2</sub> studies.

### 3.5.3.4 Category-specific recalculations

There have been no recalculations performed for this source category this year.

### 3.5.3.5 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 3.5.3.6 Activities and plans

Stø formation was perforated in April 2011 and is currently injecting in this zone. Injection was monitored every week by a fall-off test performed during stable conditions. During 2014 monitoring was done monthly by the fall-off test. Injection of CO<sub>2</sub> has been stable and there are no well integrity issues related to operation of the well.

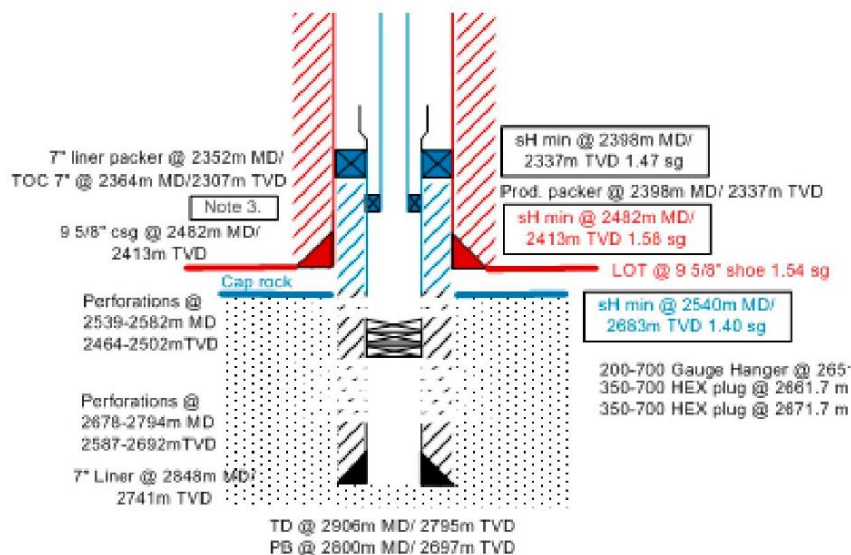


Figure 3-34. CO<sub>2</sub> injector current completion. Source: Equinor (Statoil)

The challenge of production CO<sub>2</sub> from Snøhvit field has led to a great effort to find solutions that makes the CO<sub>2</sub> injection as robust as possible. The authorities have been

kept informed about the situation and the activities and measures planned. A monitoring program covering the period 2011-2020 has been submitted to the environmental authorities.

A new injector well, G-4H, has been established and was put into operation 4Q 2016. This well has been the primary injection well since 2017.

The 4D seismic monitoring has worked well up to date. However, results from the latest seismic surveys (2019 and 2022) indicate that the 4-D seismic images will become more difficult to interpret because the signals from dissolved HC interfere with signals from CO<sub>2</sub> due to pressure fall in the formation (see figure 3.22).

### **3.5.3.7 CO<sub>2</sub> projects outside Equinor using Snøhvit data**

The EU project CO<sub>2</sub>ReMoVe plans to perform a complete performance and risk assessment for the Snøhvit project by complementing the work done under the CASTOR umbrella. Particular attention will be paid to potential vertical CO<sub>2</sub> migration to the upper gas field and lateral migration, potential flow through deteriorated wells and through undetected faults. The geochemical interaction between CO<sub>2</sub>, fluids and rock and coupling with geomechanical effects will be investigated.

Data from Snøhvit is released to the FME SUCCESS Centre (Centre for Environment-Friendly Energy Research; Subsurface CO<sub>2</sub> Storage- Critical Elements and Superior Strategy). Based on this information, specific research tasks may be defined.

## **3.6 Cross-cutting issues**

### **3.6.1 Sectoral versus reference approach**

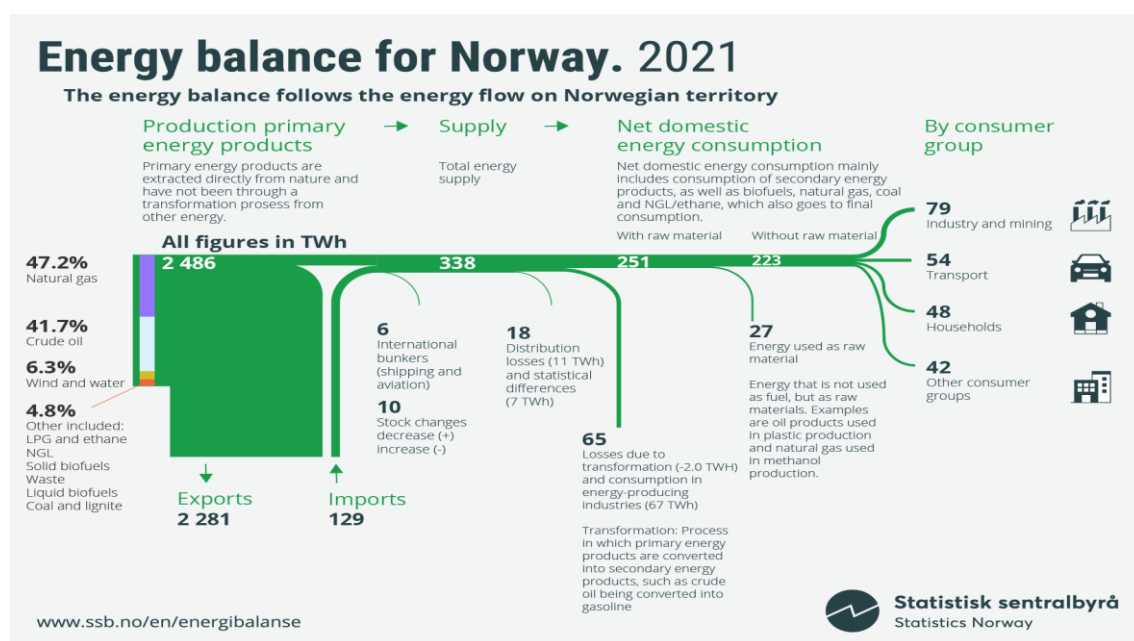
This chapter describes the current status of the RA/SA comparison. Further information on methods and results is given in annex XIII. The chapter also includes a comparison of the RA supply data to data reported to the IEA/Eurostat.

#### **3.6.1.1 Comparison of the Reference Approach with the Sectoral Approach**

The difference between the fuel consumption in the RA and SA ranges from about -9 to +51 per cent. The differences for CO<sub>2</sub> emissions ranges between -4 and +58 per cent. The highest discrepancy for CO<sub>2</sub> is in 1991, 1999-2001 and in 2004-2006. For 2021, the difference for fuel consumption is 8.5 per cent and for CO<sub>2</sub> 5.7 per cent.



The reference approach may be an important tool for verification of the sectoral approach used in the inventory. The analyses undertaken in the present and the previous NIRs have shown that the difference between RA and SA is mainly due to the statistical difference in the energy balance, and that important parts of the consumption block in the EB are unlikely to have major completeness issues. If the statistical differences are due to problems in the supply block of the balance, then resolving these problems will only affect the RA, but not the SA and the reported emissions.



A large statistical difference relative to national consumption is not unreasonable in Norway, given the large production and export share. With reference to the IPCC Guidelines 2006, Volume 2 Energy, chapter 6.8 "It should be noted that for countries that produce and export large amounts of fuel, the uncertainty on the residual supply may be significant and could affect the Reference Approach". In 2021 the production of primary energy products was 2 486 TWh. The export was 2 281 TWh, which means that more than 90 per cent of the production was exported. The total energy supply was 327 TWh, which is less than 15 per cent of the primary energy production. This means that even moderate statistical differences compared to the primary energy production, will be large compared to the energy supply.

The main results of the RA/SA comparison are shown in Table 3.41 below. The difference between RA and SA was largest in 2000, and for this year the difference in energy terms was almost 51 per cent relative to the SA. Despite this, the RA/SA difference was not larger

than 2.8 per cent compared to total production of primary energy products. During the last five years we find the largest difference between RA and SA in 2017. The RA/SA difference was 9.5 per cent of SA in 2017, but less than 0.6 per cent relative to total energy production. In order for the difference between RA and SA to be below 2% or 5% in 2017, the difference would have to be no more than 0.12 or 0,3 per cent relative to the total production of primary energy products.

For Other Fossil Fuels (waste), SA is higher than RA, resulting in a RA-SA difference ranging from -20 to -49 per cent. The problem is that figures for waste in Sectoral approach includes the non-fossil fraction of the waste, which is not included in the figures from the reference approach. When compensating for the non-fossil fraction of the waste, the remaining differences between RA and SA is not higher than 11 per cent in any year, and for the last 10 years there are no differences that are more than 1 per cent.

**Table 3.41 Comparison of fuel consumption and CO<sub>2</sub> emission data between the Reference Approach<sup>1</sup> (RA) and the Sectoral Approach (SA). 1990-2021.**

| Year | Fuel consumption              |         |                      | CO <sub>2</sub> emissions     |         |                      |
|------|-------------------------------|---------|----------------------|-------------------------------|---------|----------------------|
|      | RA, apparent consumption (PJ) | SA (PJ) | Difference RA-SA (%) | RA, apparent consumption (PJ) | SA (PJ) | Difference RA-SA (%) |
| 1990 | 343                           | 358     | -4.2                 | 25 414                        | 24 627  | 3.2                  |
| 1995 | 413                           | 407     | 1,4                  | 29 255                        | 27 773  | 5.3                  |
| 2000 | 650                           | 431     | 50.8                 | 46 348                        | 29 329  | 58.0                 |
| 2005 | 622                           | 479     | 30,0                 | 43 645                        | 32 569  | 34.0                 |
| 2010 | 624                           | 537     | 16.2                 | 42 620                        | 35 310  | 20.7                 |
| 2011 | 493                           | 518     | -4.8                 | 33 857                        | 34 270  | -1.2                 |
| 2012 | 534                           | 512     | 4.2                  | 36 258                        | 33 841  | 7.1                  |
| 2013 | 576                           | 522     | 10.4                 | 39 673                        | 34 045  | 16.5                 |
| 2014 | 573                           | 530     | 8.2                  | 39 114                        | 34 733  | 12.6                 |
| 2015 | 576                           | 531     | 8.3                  | 39 285                        | 34 889  | 12.6                 |
| 2016 | 500                           | 523     | -4.4                 | 33 378                        | 34 226  | -2.5                 |
| 2017 | 566                           | 517     | 9.5                  | 39 010                        | 33 760  | 15.6                 |
| 2018 | 555                           | 512     | 8.5                  | 37 861                        | 33 958  | 11.5                 |
| 2019 | 492                           | 499     | -1.3                 | 33 248                        | 32 929  | 1.0                  |
| 2020 | 484                           | 476     | 1.5                  | 32 705                        | 31 355  | 4.3                  |
| 2021 | 491                           | 469     | 4.6                  | 33 550                        | 30 912  | 8.5                  |

Source: Statistics Norway/Norwegian Environment Agency

<sup>1</sup> Apparent energy consumption (excluding non-energy use, reductants, and feedstocks)



Annex XII presents further data on the effect of statistical differences and other items in the energy balance.

### **3.6.1.2 Comparison of the Reference Approach with international data**

The issue of consistency between the Reference Approach and IEA energy balance data has been raised in several revision reports. This section describes work that has been done at Statistics Norway to improve reporting and give the status.

Improving the consistency between energy balance data reported to different international agencies was one of the objectives in a project in 2015-2018 at Statistics Norway for a new platform for the energy balance and energy accounts.

Results from the new energy balance were published in 2017, with revisions of the time series back to 2010. In 2018, the revision was extended back to 1990, and the results were incorporated in the emission inventory. Revised emission data were first used in reporting to the UNFCCC in the 2019 submission. RA data are now generally consistent with the published energy balance. A few exceptions (LNG bunkers and waste) are described below.

Reporting to the IEA/Eurostat using the Joint Questionnaires now uses the same data extraction methods and the same database as the national energy balance as published by Statistics Norway and the energy data supplied to the emission inventory. However, some discrepancies will occur due to different definitions and delimitations. There may also be some differences due to the timing of when data is extracted from the database for different purposes.

Differences in updating: Due to continuous improvement of the new energy balance, many data have been revised after the first publication in 2017. For several reasons, not all revisions have been reported to the IEA and Eurostat. First, revisions for the period 1990-2010 have been performed mainly for maintaining consistent time series in the emission reporting. For these years, the revised data do not have the details required for IEA/Eurostat reporting. Thus, only revised data for 2010 onwards have been resubmitted to these agencies.

For these reasons, the following discussion will focus on 2021 data.

IEA and Eurostat receive the same reporting tables from Norway. However, when the agencies present Norwegian data in energy terms (TJ, ktoe, etc.), the results differ due to

different principles for the use of conversion factors (net calorific values, NCVs). Eurostat generally uses the NCVs supplied by Norway, while the IEA uses another data set. Hence, we first present a comparison between the CRF Reference Approach and Eurostat energy balance. Table 3.42 shows 2021 energy supply data from the RA and Eurostat by fuel groups.

**Table 3.42 Comparison of energy data in the CRF Reference Approach to data published by Eurostat. 2021.**

|              | CRF Reference Approach, PJ |      |       |         |              |            | Eurostat, PJ |      |       |         |              |            |
|--------------|----------------------------|------|-------|---------|--------------|------------|--------------|------|-------|---------|--------------|------------|
|              | Prod.                      | Imp. | Exp.  | Bunkers | Stock change | App. cons. | Prod.        | Imp. | Exp.  | Bunkers | Stock change | App. cons. |
| Liquid       | 4 089                      | 375  | 4 104 | 19      | -42          | 383        | 4 071        | 366  | 4 101 | 18      | -41          | 360        |
| Solid        | 4                          | 34   | 2     | -       | -0           | 36         | 3            | 34   | 2     | -       | -0           | 35         |
| Gaseous      | 4 221                      | 6    | 4 009 | -       | 5            | 213        | 4 221        | 6    | 4 009 | 2       | 5            | 210        |
| Other fossil | 11                         | -    | -     | -       | -            | 11         | 11           | -    | -     | -       | -            | 11         |
| Total        | 8 325                      | 415  | 8 115 | 19      | -37          | 643        | 8 307        | 406  | 8 112 | 20      | -36          | 616        |

|              | Difference, PJ |      |      |         |              |            | Difference, per cent (base: Eurostat) |      |      |         |              |            |
|--------------|----------------|------|------|---------|--------------|------------|---------------------------------------|------|------|---------|--------------|------------|
|              | Prod.          | Imp. | Exp. | Bunkers | Stock change | App. cons. | Prod.                                 | Imp. | Exp. | Bunkers | Stock change | App. cons. |
| Liquid       | 17,4           | 8,9  | 2,8  | 0,7     | -0,4         | 23,3       | 0,4                                   | 2,4  | 0,1  | 3,6     | 1,0          | 6,5        |
| Solid        | 0,5            | -0,0 | -0,0 | -       | 0,0          | 0,5        | 15,8                                  | -0,0 | -0,0 | .       | -0,0         | 1,5        |
| Gaseous      | 0,0            | -0,0 | -0,0 | -2,4    | -0,0         | 2,6        | 0,0                                   | -0,0 | -0,0 | -100,0  | -0,0         | 1,2        |
| Other fossil | 0,2            | -    | -    | -       | -            | 0,2        | 1,9                                   | .    | .    | .       | .            | 1,9        |
| Total        | 18,2           | 8,9  | 2,8  | -1,8    | -0,4         | 26,7       | 0,2                                   | 2,2  | 0,0  | -8,7    | 1,2          | 4,3        |

Sources: CRF Reference Approach. Eurostat data in ktOE downloaded from <https://ec.europa.eu/eurostat/web/energy/data/energy-balances>

The table shows that apparent consumption (primary energy supply) was 26.7 PJ or 4.3 per cent higher in the RA than by Eurostat. The main reasons are NCV differences for NGL production and export, and inclusion of biofuels in RA data for refinery feedstocks. Some issues raised by the table:

- For *liquid* fuels, the main differences relate to production data for NGL. Production according to the RA was approximately 17 PJ higher than by Eurostat. This is due to inconsistent NCV values. In the RA and the published energy balance, an NCV value of 46.1 TJ/kt is used for NGL (akin to the LPG value). In IEA/Eurostat reporting, a value of 43.8 TJ/kt is used.

- A similar but smaller NCV effect relates to export which is recorded as NGL in the RA, but as naphtha by Eurostat. The NCV difference is the same as for production. The net difference in export was 2 PJ.
- For refinery feedstocks, the RA includes an amount in imports that are actually biofuels for blending at refineries. This amount is not included in Eurostat data, which comprise only fossil additives. The difference was 8 PJ. Due to different reporting guidelines, the supply of additives is recorded as import in the RA, but as primary production by Eurostat.
- For *solid* fuels coal production is 0.5 PJ (16 per cent) higher in the RA because production at Svalbard by Russian companies were included. This production is not included in the energy balance.
- For *gaseous* d, the main difference relates to international bunkers. The CRF does not allow data for bunkers of gaseous fuels. Thus, the RA apparent consumption is 0.2 PJ too high, relative to both Eurostat and the published energy balance. Thus, the difference is -100 per cent.
- For *other fossil fuels* (waste) there are minor differences.

Note on NCVs: The NCV given in CRF table 1.A(b) is valid for apparent consumption only. It is not valid for production/export. Domestic consumption of natural gas is dominated by rich gas used in the offshore oil and gas sector and has a NCV which is significantly higher than the value for exported gas. Thus, using the RA NCV for production/export is misleading and would show discrepancies to IEA/Eurostat that are not actual. The proper NCVs are shown in annex XII, table AXII-1, and the TJ data in [Table 3.42](#) were prepared using these values.

*IEA comparison:* The analysis of IEA data was published in the NIR 2021 based on 2019 data and has not been repeated due to data availability. – Comparison with IEA data is less straightforward because for most liquid fuels, the IEA uses NCV values that differ from the ones reported by Statistics Norway (and generally used by Eurostat). For *secondary products*, the IEA uses a set of regional default net calorific values for "OECD Europe". For *crude oil*, the IEA Secretariat estimates NCVs based on the oil product outputs of the oil refineries in order to close the refining energy balance. For the last five years, this method gives an NCV that is 2-3 per cent higher than the value used in the reporting to the IEA. As the contribution from crude oil to the apparent consumption is in the order of 500-600 PJ (14-15 Mt), the IEA apparent consumption is 10-15 PJ higher. The effect on production and export in absolute terms is of course much higher.

### 3.6.2 Feedstocks and non-energy use of fuels

Emissions from the use of feedstock are, in accordance with the IPCC guidelines, generally accounted for in the industrial processes sector in the Norwegian inventory. By-products

from processes like blast furnace gas and fuel gas from ethylene cracking that are sold and combusted in other sectors are accounted for and reported under the energy sector.

### **3.6.2.1 Fuel quantity for Non-Energy Use (NEU)**

In CRF table 1A(d), "Fuel quantity for NEU" is generally filled in with data for item "11 *Non-energy consumption*" according to the energy balance. These amounts are shown in blue colour in the figures below.

The non-energy consumption is adjusted with respect to reducing agents that are considered as *final energy consumption* in the energy balance but accounted as IPPU emissions in the inventory. This mainly concerns coal and coke, which are mostly accounted as energy use in the energy balance. Note that these adjustments are also obtained from the energy balance. The primary data includes information on whether the fuels are used for regular combustion or for metallurgical or other processes, even if the utilization of the heat means that it is accounted as "energy use".

The non-energy consumption is also adjusted with respect to combustion emissions that are accounted under IPPU, in accordance with the IPCC guidelines. This applies to emissions from petrochemical and ammonia plants reported in sectors 2.B.1 and 2.B.8. In these cases, all consumption of the relevant fuels (LPG, natural gas) at the plants are reported as NEU, not only the amount that is recorded as feedstock in the energy balance.

Fuel quantities for non-energy use that correspond to final energy consumption are shown in yellow colour in the figures below.

Some fuels are aggregated in the same manner as in CRF table 1A(b). In particular, ethane is reported with LPG and anthracite is reported with other bituminous coal.

### **3.6.2.2 Carbon excluded**

CRF table 1A(d) also includes information of the amount of carbon excluded. The excluded amount corresponds to the fuel quantity (using the same factors for carbon content as in table 1A(b)), except for emissions from petroleum products that are included as energy combustion in 1A as described in the following paragraph.

### **3.6.2.3 CO<sub>2</sub> emissions from non-fuel use reported in 1A Fuel combustion**

These emissions comprise the following categories, which are further described in section 3.2.11:

- A fraction of non-fuel use of gasoline, gas/diesel oil and residual fuel oil is assumed to be emitted to air. The emissions are reported under 1A5a *Non-fuel use*.

- Emissions from use of lubricants in 2-stroke engines are reported under 1A5b. Emissions from other lubricants are on the other hand reported in IPPU under 2D2 *Lubricants* and are as such accounted as carbon excluded.

#### 3.6.2.4 CO<sub>2</sub> emissions from non-fuel use reported in 2. IPPU

Emissions reported in IPPU source categories that correspond to the carbon excluded are listed in CRF table 1A(d). Many industries use several fuels, and an aggregate level of reporting is shown. For transparency, emissions from IPPU sectors are entered exactly as reported. Balances for the major fuels are shown in the figures below, and possible discrepancies between the reported emissions and the CO<sub>2</sub> excluded from the reference approach are described in more detail.

*Liquefied petroleum gases (LPG)*, including ethane, are used as a feedstock in ammonia and ethylene production. Products and secondary fuels<sup>11</sup> from ethylene cracking are used as feedstock and fuel in adjacent petrochemical plants. All emissions deriving from LPG in ammonia production and ethylene cracking are reported in IPPU, including combustion emissions and emissions at adjacent plants that use secondary fuels from the cracking.

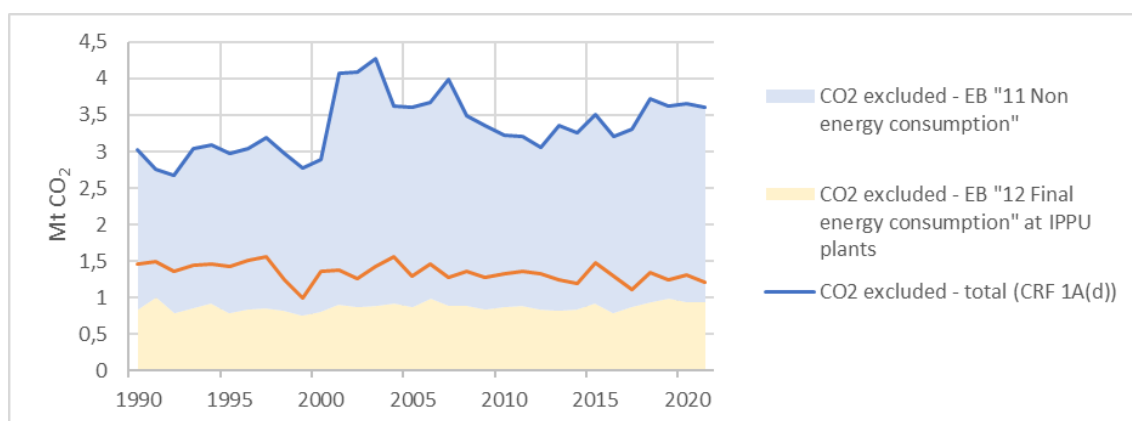


Figure 3-35. LPG. CO<sub>2</sub> amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:

- 2B1 Ammonia
- 2B8b Ethylene (including vinyl chloride reallocated from 2Bc)
- 2B8g Plastics (PE/PP production)
- 2H2 Food and beverage (CO<sub>2</sub> as product from ammonia production)

Figure 3-35 shows CO<sub>2</sub> excluded from the reference approach and CO<sub>2</sub> reported in IPPU. Non-fuel consumption according to the energy balance is shown in blue shading. CO<sub>2</sub> from fuels reported as energy use in the balance is shown in yellow shading. This corresponds to

<sup>11</sup> Including "fuel gas" which is reported as "Other oil products n.e.c." in the energy balance.

most of the emissions in 2B8. The area between the yellow shading and the orange line corresponds to emissions at ammonia plants from fuels recorded as non-fuel use in the energy balance, and to small emissions from flaring and derived fuels in petrochemical plants. The area above the orange line corresponds to carbon sequestered in products.

Recovered CO<sub>2</sub> emissions from ammonia production, which are reported in 2H2 *Food and beverage production*, are included here. However, emissions in 2H2 are adjusted for export and import of bulk CO<sub>2</sub>. Thus, the emissions do not correspond precisely to the energy balance data.

Secondary fuels (fuel gas) that are sold to plants in other sectors are excluded from both NEU quantity and IPPU emissions. These fuel amounts and their emissions are accounted for in sector 1A.

*Petroleum coke* is used as a feedstock primarily in production of aluminium and carbides, and of electrodes for use in the metallurgical industry.

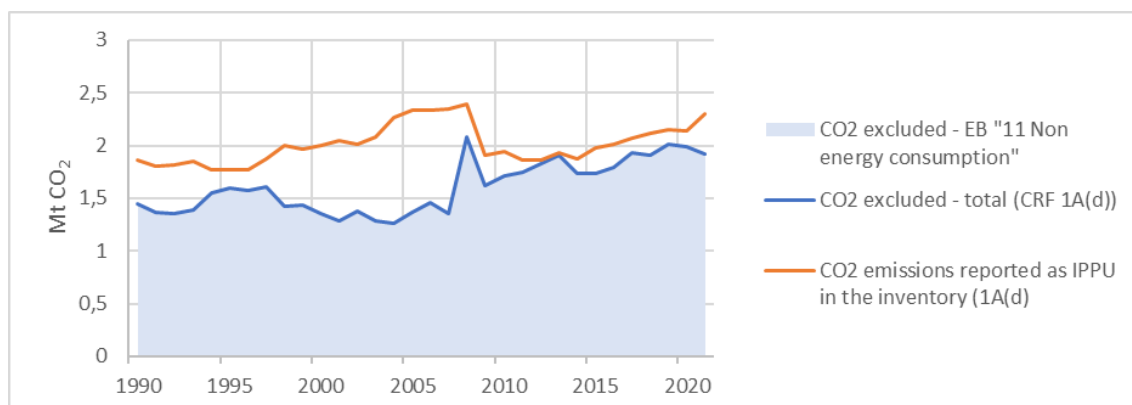


Figure 3-36. Petrol coke. CO<sub>2</sub> amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:

- 2B5 Carbide production
- 2C3 Aluminium production
- 2C7 (part) Anodes

The emissions from the included sectors are higher than the total non-fuel consumption of petrol coke (Figure 3-36). This is partly due to foreign trade in electrodes and electrode materials. This foreign trade is not included in the energy balance. Norway was a net importer of electrodes until 2008, when a new plant for prebaked anodes to aluminium production opened. Since then, imports and exports of electrodes have more or less balanced.

The decrease in difference between reported emissions and CO<sub>2</sub> excluded in the last decade is partly offset by an increase in the same difference for coal and coke (see below).

Other discrepancies between the NEU quantity and the IPPU emissions as shown include:

- Small amounts of petroleum coke and electrode materials are used for non-energy purposes in other metal production, particularly in ferroalloy plants.
- Some of the emissions from anode productions are actually from coal, coke or pitch.

*Coal and coke products* are presented jointly. Many metallurgical plants use several products in large amounts. In CRF table 1A8(d), IPPU emissions from categories that predominantly use coal and coke are aggregated under "Other bituminous coal". Note that all metallurgical industry in Norway is electricity intensive. There are no primary iron or steel plants that use coal and coke as their main energy source.

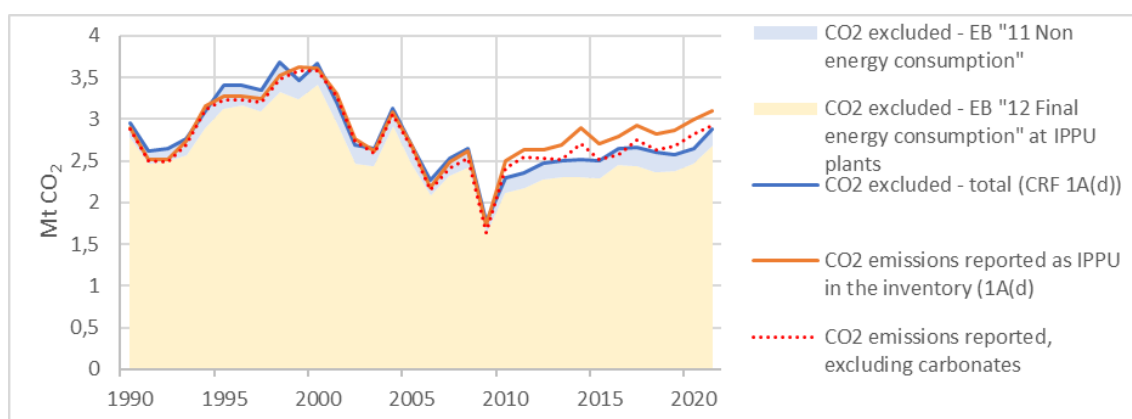


Figure 3-37. Coal and coke products. CO<sub>2</sub> amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:

- 2B6 Titanium dioxide
- 2C Metal production, excluding 2C3 and 2C7-anodes (petroleum coke) and 2C7-nickel (carbonates only)

Figure 3-37 shows CO<sub>2</sub> excluded from the reference approach and CO<sub>2</sub> reported in IPPU. In the energy balance, all coke and most of the coal are recorded as energy use. This is shown in yellow shading. Only a small fraction of coal consumption is recorded as non-fuel consumption into the energy balance, as shown in blue shading.

An increasing amount of the CO<sub>2</sub> reported from ferroalloy production is from carbonates, partly from lime and dolomite and partly from carbonate ores. The dotted line in the figure shows IPPU emissions excluding carbonate CO<sub>2</sub>. When adjusted for carbonate CO<sub>2</sub>, there is a close correspondence between the NEU quantity from the energy balance and the emissions throughout the reporting period.

The discrepancies mentioned for petroleum coke above applies also to coal and coke, in the reverse way. A small fraction of the IPPU emissions is actually from petrol coke. On the other hand, some emissions originating from coal and coke in anode production are excluded from the figure.

Secondary fuels (blast furnace gas) that are sold to plants in other sectors are excluded from both NEU quantity and IPPU emissions. These fuel amounts and their emissions are accounted for in sector 1A.

Natural gas is used as feedstock at a methanol plant. There are no other significant uses of natural gas as feedstock.

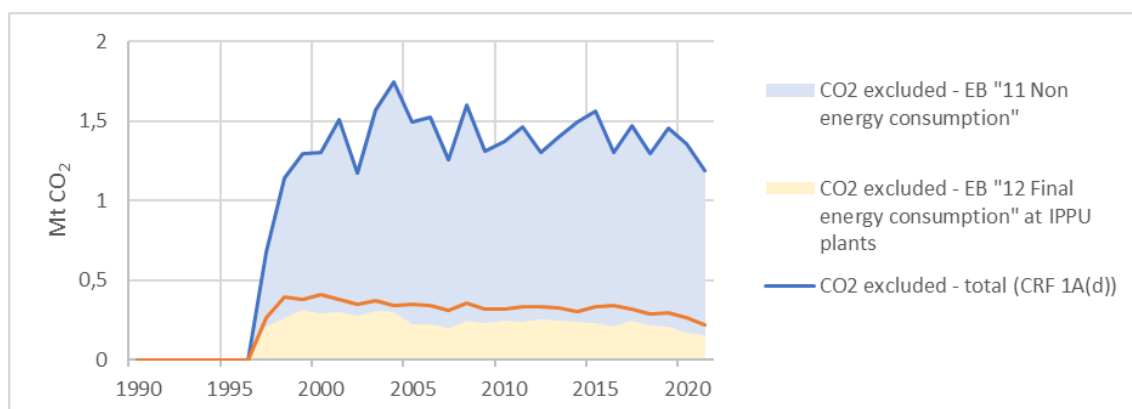


Figure 3-38. Natural gas. CO<sub>2</sub> amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:

- 2B8a Methanol

Figure 3-38 shows CO<sub>2</sub> excluded from the reference approach and CO<sub>2</sub> reported in IPPU. The picture is similar to that for LPG, but emissions from fuel recorded as feedstock in the energy balance are much smaller.

Non-fuel consumption according to the energy balance is shown in blue shading. CO<sub>2</sub> from fuels reported as energy use in the balance is shown in yellow shading. This corresponds to emissions in 2B8a. The area between the yellow shading and the orange line corresponds to emissions from flaring and fuels derived from the feedstock. The area above the orange line corresponds to carbon sequestered in products.



*Paraffin wax* and *white spirits* and related products have not been included in table 1A(d). Paraffin wax is not included in the Norwegian energy balance. White spirits etc. is only included in the supply side of the balance, and only in small amounts. No final use is recorded. Emissions from these products are reported in the IPPU sector as 2D2 "Paraffin wax use" and 2D3-i Solvent use. These emissions are based on activity data from other sources than the energy balance.

As a *summary*, the balances for LPG and natural gas show how emissions from both energy use and feedstocks are reported in the IPPU sectors. Most of the feedstocks are sequestered in products. For petroleum coke, coal and coke used in the metallurgical industry, reported emissions are slightly higher than the CO<sub>2</sub> excluded from the reference approach. Several causes for this gap are discussed. The gap for these three fuels combined is more stable over the inventory period than shown in the individual balances.

## 3.7 Memo items

### 3.7.1 International bunkers

#### 3.7.1.1 Description

Emissions from international marine and aviation bunker fuels are excluded from the national totals, as required by the IPCC Guidelines (IPCC 2006). The estimated emission figures are reported separately and are presented in Table 3.43.

In 2021 CO<sub>2</sub> emissions from ships and aircraft in international traffic bunkered in Norway amounted to a total of 1.5 million tonnes, which corresponds to 3% of the total Norwegian CO<sub>2</sub> emissions.

During the period 1990-2021, emissions of CO<sub>2</sub> from marine bunkers decreased by 43 per cent. The emissions have varied greatly in this period and reached a peak in 1997. Thereafter there has been a descending trend in emissions.

The CO<sub>2</sub> emissions from international air traffic bunkered in Norway in 2021 was 0.5 million tonnes. The emissions in 2021 were 20 per cent lower than in 1990 due to the covid-19 pandemic. In 2021 the emissions were 8 per cent lower than in 2020.

**Table 3.43 Emissions from ships and aircraft in international traffic bunkered in Norway, 1990-2021. 1000 tonnes.**

|      | Aviation        |                 |                  | Marine          |                 |                  |
|------|-----------------|-----------------|------------------|-----------------|-----------------|------------------|
|      | CO <sub>2</sub> | CO <sub>2</sub> | N <sub>2</sub> O | CO <sub>2</sub> | CO <sub>2</sub> | N <sub>2</sub> O |
| 1990 | 643             | 0.008           | 0.034            | 2302            | 0.166           | 0.255            |

|      |      |       |       |      |       |       |
|------|------|-------|-------|------|-------|-------|
| 1991 | 583  | 0.007 | 0.031 | 2009 | 0.145 | 0.222 |
| 1992 | 625  | 0.007 | 0.033 | 2157 | 0.156 | 0.239 |
| 1993 | 634  | 0.007 | 0.033 | 2136 | 0.154 | 0.236 |
| 1994 | 617  | 0.007 | 0.033 | 2071 | 0.15  | 0.229 |
| 1995 | 563  | 0.006 | 0.03  | 2294 | 0.166 | 0.253 |
| 1996 | 668  | 0.007 | 0.035 | 2581 | 0.186 | 0.287 |
| 1997 | 746  | 0.008 | 0.039 | 3123 | 0.226 | 0.348 |
| 1998 | 797  | 0.008 | 0.042 | 3109 | 0.225 | 0.346 |
| 1999 | 918  | 0.009 | 0.048 | 2907 | 0.21  | 0.321 |
| 2000 | 886  | 0.009 | 0.047 | 2831 | 0.205 | 0.317 |
| 2001 | 804  | 0.008 | 0.042 | 2775 | 0.2   | 0.311 |
| 2002 | 706  | 0.007 | 0.037 | 2292 | 0.166 | 0.255 |
| 2003 | 721  | 0.007 | 0.038 | 2159 | 0.156 | 0.239 |
| 2004 | 810  | 0.007 | 0.043 | 2134 | 0.154 | 0.235 |
| 2005 | 910  | 0.008 | 0.048 | 2597 | 0.188 | 0.283 |
| 2006 | 1094 | 0.009 | 0.058 | 2380 | 0.172 | 0.258 |
| 2007 | 1133 | 0.01  | 0.06  | 2434 | 0.176 | 0.261 |
| 2008 | 1121 | 0.009 | 0.059 | 2219 | 0.16  | 0.234 |
| 2009 | 1084 | 0.009 | 0.057 | 2135 | 0.154 | 0.221 |
| 2010 | 1289 | 0.01  | 0.068 | 1682 | 0.122 | 0.171 |
| 2011 | 1357 | 0.011 | 0.072 | 1694 | 0.122 | 0.169 |
| 2012 | 1505 | 0.012 | 0.081 | 1605 | 0.116 | 0.157 |
| 2013 | 1596 | 0.012 | 0.086 | 1500 | 0.108 | 0.144 |
| 2014 | 1678 | 0.013 | 0.091 | 1151 | 0.083 | 0.108 |
| 2015 | 1623 | 0.012 | 0.088 | 1102 | 1.400 | 0.098 |
| 2016 | 1587 | 0.012 | 0.086 | 899  | 1.867 | 0.075 |
| 2017 | 1669 | 0.012 | 0.092 | 995  | 1.726 | 0.081 |
| 2018 | 1748 | 0.012 | 0.096 | 1121 | 1.999 | 0.088 |
| 2019 | 1743 | 0.012 | 0.096 | 1044 | 2.090 | 0.078 |
| 2020 | 555  | 0.005 | 0.031 | 974  | 2.291 | 0.069 |
| 2021 | 513  | 0.005 | 0.028 | 993  | 2.287 | 0.068 |

### 3.7.1.2 Shipping

#### 3.7.1.2.1 Methodological issues

Emissions are calculated by multiplying activity data with emission factors. The sales statistics for petroleum products, which is based on reports from the oil companies to Statistics Norway, has figures on sales for bunkers of marine gas oil, heavy distillates, and heavy fuel oil. The same emission factors as in the Norwegian national calculations are

used.

#### 3.7.1.2.2 Activity data

Sales figures for international sea transport from Statistics Norway's sales statistics for petroleum products are used for marine gas oil, heavy distillates, and heavy fuel oil.

#### 3.7.1.2.3 Emission factors

Emission factors used for shipping are described under *Navigation* in Section 3.2.7.4.

### 3.7.1.3 Aviation

#### 3.7.1.3.1 Methodological issues

The calculation method for aviation is based on a "bottom up" calculation of jet kerosene consumption and emissions from aviation based on traffic data, emission factors and energy use factors for aircraft types (kg / km). Since traffic data also includes foreign flights, it is possible to link calculations of foreign and domestic aviation directly to activity data. Figures included in international aviation (bunker) is emissions from jet kerosene, bio jet kerosene and aviation gasoline consumption from flights departing from a Norwegian airport and arriving in a different country.

#### 3.7.1.3.2 Activity data

Statistics Norway annually collects data on sales of jet kerosene and aviation gasoline in the sales statistics of petroleum products in addition to use of fuel from the air traffic companies, including specifications on domestic use and purchases of fuel in Norway and abroad. Activity data on flight movements are collected annually from Avinor (a Norwegian state-owned company and Norway's largest owner of airports).

#### 3.7.1.3.3 Emission factors

Emission factors used for *Aviation* are described under *Aviation* in Section 3.2.4.4.

### 3.7.2 CO<sub>2</sub> emissions from biomass

Emissions are estimated from data in the energy accounts on use of different forms of biomass, such as wood, wood waste and black liquor, as well as biofuels and biogas. According to the guidelines, CO<sub>2</sub> emissions from these fuels are not included in the national total in the Norwegian emission inventory but are reported as memo items in the CRF.

Emission factors for biomass fuels are shown in [Table 3.4](#). Details are given in the sector chapters where necessary.

## 4. Industrial processes and product use (CRF sector 2)

### 4.1 Overview of sector

The chapter provides descriptions of the methodologies used to calculate emissions of greenhouse gases from industrial processes and product use (IPPU).

Norway has a long experience of using GHG emissions from industrial point sources in the national GHG inventory in the IPPU sector and in the Energy sector. For most IPPU categories, plant-level process emissions are aggregated to estimate national-level emissions. A large share of the GHG emissions from industrial processes included in the Norwegian GHG inventory are therefore from annual reports sent by each plant to the Norwegian Environment Agency. Such annual reports are reports as required by their regular permit, reports as required by the permit under the EU emission trading system (EU ETS) and reports as required by a voluntary agreement up to the year 2012 when the agreement terminated.

The Norwegian Environment Agency has been given the authority to manage and enforce the Pollution Control Act, the Product Control Act and the Greenhouse Gas Emission Trading Act. The Norwegian Environment Agency grants permits, establishes requirements, and sets emission limits, and carries out inspections to ensure compliance. This is one of the core responsibilities of the agency.

The rest of the emissions included in the inventory are calculated by Statistics Norway. The calculations are based on emission factors and activity data. The emission factors are collected from different sources, while the activity data used in calculations carried out by Statistics Norway is from official statistics normally collected by Statistics Norway.

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. Chapter 2 of Annex VII describes a major QA/QC exercise in 2006 on consistent time series from 1990 to 2004 from the largest industrial plants in Norway. Several data sources were used to fill data gaps and establish a consistent time series. If no reference is made to data filling in the various source categories, any data filling was done as part of the QA/QC exercise in 2006. Chapter 3 of Annex VII describes the current QA/QC procedures and the data sources used.

Norway includes indirect emissions of CO<sub>2</sub> from oxidized CH<sub>4</sub> and NMVOC for some IPPU source categories in its GHG inventory, but these emissions are not reported in the IPPU sector. Instead, the emissions are reported in CTF table 6. Chapter 9 gives an overview of the source categories from which indirect CO<sub>2</sub> emissions are estimated and the overall level and trend. The indirect emissions of CO<sub>2</sub> are calculated by Statistics Norway and are based on the emissions of CH<sub>4</sub> and NMVOC. This chapter on IPPU describes the methodologies etc for the source categories from which indirect CO<sub>2</sub> is estimated.

Table 4.1 gives an overview of the Norwegian IPPU sector. The GHG emissions from IPPU in 2021 were about 9.0 million tonnes CO<sub>2</sub> equivalents and the emissions in 1990 were 14.7 million tonnes CO<sub>2</sub> equivalents. The emissions from this source category have decreased by 38.7% from 1990 to 2021 and increased by 0.1% from 2020 to 2021. The decrease from 1990 to 2021 is mainly due to reduced PFC emissions from production of aluminium and SF<sub>6</sub> from production of magnesium. The reduction in the SF<sub>6</sub> emissions is due to the closing down of production of cast magnesium in 2002, improvements in the gas insulated switchgear (GIS) sector and an almost end in the use of SF<sub>6</sub> as tracer gas. In June 2006, the magnesium recycling foundry also closed. In addition, N<sub>2</sub>O emissions from nitric acid production have decreased substantially since 1990.

| <b>Table 4.1 Emission trends for IPPU categories (tonnes CO<sub>2</sub> equivalents).</b> |            |                       |           |           |                       |                            |                           |
|-------------------------------------------------------------------------------------------|------------|-----------------------|-----------|-----------|-----------------------|----------------------------|---------------------------|
| Category                                                                                  | 1990       | 1990,<br>% of<br>IPPU | 2020      | 2021      | 2021,<br>% of<br>IPPU | Trend<br>1990-<br>2021 (%) | Trend<br>2020-2021<br>(%) |
| 2A                                                                                        | 727 694    | 5.0                   | 963 773   | 935 770   | 10.4                  | 28.6                       | -2.9                      |
| 2B                                                                                        | 3 899 081  | 26.5                  | 1 989 032 | 1 839 342 | 20.4                  | -52.8                      | -7.5                      |
| 2C                                                                                        | 9 780 583  | 66.5                  | 4 985 777 | 5 317 827 | 59.0                  | -45.6                      | 6.7                       |
| 2D                                                                                        | 173 304    | 1.2                   | 104 716   | 104 399   | 1.2                   | -39.8                      | -0.3                      |
| 2E                                                                                        | -          | 0.0                   | 1 175     | 1 175     | 0.0                   | NA                         | 0.0                       |
| 2F                                                                                        | 49         | 0.0                   | 749 797   | 628 423   | 7.0                   | 1286245.3                  | -16.2                     |
| 2G                                                                                        | 85 391     | 0.6                   | 87 489    | 74 935    | 0.8                   | -12.2                      | -14.3                     |
| 2H                                                                                        | 31 272     | 0.2                   | 119 580   | 112 690   | 1.3                   | 260.4                      | -5.8                      |
| Total                                                                                     | 14 697 375 | 100.0                 | 9 001 340 | 9 014 561 | 100.0                 | -38.7                      | 0.1                       |

Source: Statistics Norway and the Norwegian Environment Agency

Metal industry (2C) is the largest category within IPPU, and the emissions are mainly from production of ferroalloys and aluminium. The other main contributing sectors are Chemical Industry (2B), Mineral Industry (2A) and Product uses as substitutes for ODS (2F). Table 4.2

shows the source categories in IPPU that have been identified as key categories from either approach 1 or 2 in the key category analysis.

**Table 4.2 Key categories in the sector Industrial processes and product use.**

| CRF code | Source category                           | Gas              | Key category according to approach | Method    |
|----------|-------------------------------------------|------------------|------------------------------------|-----------|
| 2A1      | Cement production                         | CO <sub>2</sub>  | 1                                  | Tier 3    |
| 2A2      | Lime production                           | CO <sub>2</sub>  | 1                                  | Tier 3    |
| 2B1      | Ammonia production                        | CO <sub>2</sub>  | 2                                  | Tier 2    |
| 2B2      | Nitric Acid Production                    | N <sub>2</sub> O | 2                                  | Tier 3    |
| 2B5*     | Carbide production                        | CO <sub>2</sub>  | 2                                  | Tier 2    |
| 2B6      | Titanium dioxide production               | CO <sub>2</sub>  | 1                                  | Tier 2    |
| 2B8**    | Petrochemical and carbon black production | CO <sub>2</sub>  | 2                                  | Tier 2    |
| 2C2      | Ferroalloys production                    | CO <sub>2</sub>  | 2                                  | Tier 2/ 3 |
| 2C3      | Aluminium production                      | CO <sub>2</sub>  | 2                                  | Tier 2/ 3 |
| 2C3      | Aluminium production                      | PFCs             | 2                                  | Tier 2    |
| 2C4      | Magnesium production                      | SF <sub>6</sub>  | 1                                  | Tier 2    |
| 2D1      | Lubricant use                             | CO <sub>2</sub>  | 1                                  | Tier 2    |
| 2D3***   | Other                                     | CO <sub>2</sub>  | 1                                  | Tier 1/ 2 |
| 2F       | Product uses as substitutes for ODS       | HFCs             | 2                                  | Tier 2    |
| 2H2      | Food and beverages industry               | CO <sub>2</sub>  | 1                                  | Tier 2    |

Source: Statistics Norway and the Norwegian Environment Agency

\* In the key category analysis, 2B5a and 2B5b have been aggregated to 2B5.

\*\* In the key category analysis, 2B8a, 2B8b and 2B8g have been aggregated to 2B8.

\*\*\* In the key category analysis, 2D3 covers 2D3d Other (use of urea).

## 4.2 Mineral industry – 2A

The sector category Mineral industry includes CO<sub>2</sub> emissions in the source categories cement production, lime production, glass production, ceramics, other uses of soda ash, non-metallurgical magnesia production and other process use of carbonates. Table 4.3 shows that components included in the inventory, the tier method used and whether the source categories are key categories or not.

**Table 4.3 Mineral industry. Component included in the inventory, tier of method and key category.**

| Source category                              | CO <sub>2</sub> | Tier   | Key category |
|----------------------------------------------|-----------------|--------|--------------|
| 2A1. Cement production                       | R               | Tier 3 | Yes          |
| 2A2. Lime production                         | R               | Tier 3 | Yes          |
| 2A3. Glass production                        | R               | Tier 3 | No           |
| 2A4a. Ceramics                               | R               | Tier 3 | No           |
| 2A4b. Other uses of soda ash                 | E               | Tier 1 | No           |
| 2A4c. Non metallurgical magnesium production | R               | Tier 3 | No           |
| 2A4d. Other process use of carbonates        | R               | Tier 2 | No           |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occuring. IE = Included Elsewhere.*

Table 4.4 shows the trends for 2A as a whole and for the various source categories. The CO<sub>2</sub> emissions from this sector category were about 0.9 million tonnes in 2021, this accounts for 10.4% of the total emission from the IPPU sector. The emissions from this sector have increased with 28.6% from 1990 to 2021, mainly due to increased production of clinker and lime in more recent years. The emissions from this sector category decreased by 2.9% from 2020 to 2021.

| <b>Table 4.4 Emission trends for 2A Mineral industry (t CO2 equivalents).</b> |         |                       |         |         |                       |                               |                               |
|-------------------------------------------------------------------------------|---------|-----------------------|---------|---------|-----------------------|-------------------------------|-------------------------------|
| Source category                                                               | 1990    | 1990,<br>% of<br>IPPU | 2020    | 2021    | 2021,<br>% of<br>IPPU | Trend<br>1990-<br>2021<br>(%) | Trend<br>2020-<br>2021<br>(%) |
| 2A1. Cement production                                                        | 634 263 | 4.3                   | 724 707 | 698 566 | 7.7                   | 10.1                          | -3.6                          |
| 2A2. Lime production                                                          | 49 848  | 0.3                   | 189 858 | 206 037 | 2.3                   | 313.3                         | 8.5                           |
| 2A3. Glass production                                                         | 5 576   | 0.0                   | 7 352   | 7 990   | 0.1                   | 43.3                          | 8.7                           |
| 2A4a. Ceramics                                                                | 3 738   | 0.0                   | 1 962   | 4 422   | 0.0                   | 18.3                          | 125.4                         |
| 2A4b. Other uses of soda ash                                                  | 8 992   | 0.1                   | -       | -       | 0.0                   | -100.0                        | NA                            |
| 2A4c. Non metallurgical magnesium production                                  | -       | 0.0                   | 23 230  | 2 728   | 0.0                   | NA                            | -88.3                         |
| 2A4d. Other process use of carbonates                                         | 25 277  | 0.2                   | 16 663  | 16 027  | 0.2                   | -36.6                         | -3.8                          |
| Total 2A.                                                                     | 727 694 | 5.0                   | 963 773 | 935 770 | 10.4                  | 28.6                          | -2.9                          |

Source: Statistics Norway and the Norwegian Environment Agency

Table 4.5 and Table 4.6 show that most of the limestone and dolomite uses within the IPPU sector are within 2A. In addition to uses in the IPPU sector, there are reported emissions in 3G from the use of limestone and dolomite.

| <b>Table 4.5 Balance in ktonnes for latest years for the use of limestone for which IPPU emissions are reported.</b> |       |       |       |       |       |       |
|----------------------------------------------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|
| Limestone use                                                                                                        | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  |
| 2A1 - Cement production                                                                                              | 1 556 | 1 740 | 1 659 | 1 640 | 1 647 | 1 588 |
| 2A2 - Lime production                                                                                                | 490   | 481   | 457   | 416   | 436   | 478   |
| 2A3 - Glass production                                                                                               | 0     | 0     | 0     | 0     | 0     | 0     |
| 2A4a - Ceramics                                                                                                      | 0     | 0     | 0     | 0     | 0     | 0     |
| 2A4c - Non-metallurgical magnesium production                                                                        | 0     | 0     | 0     | 0     | 0     | 0     |
| 2A4d - Other process uses of carbonates                                                                              | 0     | 0     | 0     | 0     | 0     | 0     |
| 2C2 - Production of ferroalloys                                                                                      | 51    | 32    | 34    | 35    | 38    | 30    |
| 2H1 - Pulp and paper                                                                                                 | 22    | 19    | 19    | 19    | 20    | 21    |
| Total limestone                                                                                                      | 2 119 | 2 272 | 2 169 | 2 111 | 2 141 | 2 116 |

Source: Statistics Norway and the Norwegian Environment Agency



| <b>Table 4.6 Balance in ktonnes for latest years for the use of dolomite for which IPPU emissions are reported.</b> |      |      |      |      |      |      |
|---------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|
| Dolomite use                                                                                                        | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| 2A2 - Lime production                                                                                               | 27   | 27   | 30   | 55   | 16   | 10   |
| 2A4c – Non-metallurgical magnesium production                                                                       | 90   | 32   | 67   | 109  | 50   | 7    |
| 2A4d – Other process uses of carbonates                                                                             | 11   | 16   | 17   | 10   | 13   | 18   |
| 2A3 - Glass production                                                                                              | 11   | 11   | 12   | 13   | 12   | 14   |
| 2C2 - Production of ferroalloys                                                                                     | 6    | 14   | 17   | 9    | 2    | 4    |
| Total dolomite                                                                                                      | 145  | 100  | 143  | 197  | 93   | 53   |

Source: Statistics Norway and the Norwegian Environment Agency

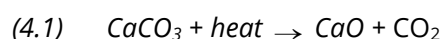
A QA/QC exercise was undertaken some years ago on all uses of limestone and dolomite used in the country. There was no information that indicated that there were other emissive uses of limestone and dolomite that were not reported, and the QA/QC exercise confirmed this. The uses with no emissions are according to the Geological Survey of Norway slurry and crushed rock for filling.

A potential use of limestone is in flue gas desulphurization (FGD), but this is not used in Norway. The industry primarily uses the sea water scrubbing technology. This combined with closures of some industrial plants, increasingly strict requirements on the sulphur content in various oil products, the introduction of a SO<sub>2</sub> tax and requirements for industry to reduce its emissions have decreased the SO<sub>2</sub> emissions.

## **4.2.1 Cement Production, 2A1 (Key category for CO<sub>2</sub>)**

### **4.2.1.1 Category description**

Two plants in Norway produce cement and they are covered by the EU ETS. The process emissions originate from the raw material calcium carbonate (CaCO<sub>3</sub>). The resulting calcium oxide is heated to form clinker and then crushed to form cement.



CO<sub>2</sub> from cement production is defined as a key category according to the approach 1 analysis.

### **4.2.1.2 Methodological issues**

The emissions of CO<sub>2</sub> from clinker production included in the GHG inventory are reported by the two producers in their annual report under their regular permit and under the EU

ETS to the Norwegian Environment Agency. Before entering the EU ETS, the plants used a tier 2 methodology while they now use a tier 3 methodology. The plants report data on the types and quantities of carbonates consumed to produce clinker, as well as their emission factors and oxidation factors. The reported emissions include Cement Kiln Dust (CKD).

#### 4.2.1.3 Activity data

The amount of clinker, CKD and other carbonates that the plants use in their calculation are reported by the plants to the Norwegian Environment Agency. The annual total clinker production is reported in the CRF Table 2(l).A-Hs1 and [Table 4.7](#) shows the clinker production for some selected years in the time series.

| <b>Table 4.7 Norwegian clinker production (ktonnes).</b> |                  |
|----------------------------------------------------------|------------------|
| Year                                                     | Total production |
| 1990                                                     | 1 244.1          |
| 1995                                                     | 1 682.9          |
| 2000                                                     | 1 649.6          |
| 2005                                                     | 1 454.3          |
| 2010                                                     | 1 433.8          |
| 2012                                                     | 1 399.1          |
| 2013                                                     | 1 399.8          |
| 2014                                                     | 1 374.9          |
| 2015                                                     | 1 284.1          |
| 2016                                                     | 1 306.3          |
| 2017                                                     | 1 461.5          |
| 2018                                                     | 1 429.4          |
| 2019                                                     | 1 406.9          |
| 2020                                                     | 1 407.1          |
| 2021                                                     | 1 360.8          |

Source: Statistics Norway and the Norwegian Environment Agency

#### 4.2.1.4 Emission factors

CO<sub>2</sub>

The emission factors used are plant specific. The factors are dependent on the chemical composition of the clinker i.e., the content of Ca and Mg. The fraction of CaO from non-carbonate sources like ashes is subtracted. The emission factors are calculated particularly for the two Norwegian plants. Prior to entering the EU ETS, the emission factors did not vary much and tended to be around 0.530 tonne CO<sub>2</sub> per tonne clinker for one plant (Tokheim 2006) and 0.541 tonne CO<sub>2</sub> per tonne clinker as recommended by SINTEF (1998c) for the

other plant. After entering the EU ETS, the plants face stricter requirements concerning how their EF are determined and the reported EFs fluctuate close to the IPCC default emission factor of 0.52 tonne CO<sub>2</sub>/tonne clinker. The same emission factors are used for CKD as for clinker production. Until 2009, both plants have used a conversion factor of 1. This means that all Ca and Mg have been assumed to be carbonates. From 2010, the largest plant has reported conversion factors that are less than 1 while the smaller plant continued to use a conversion factor of 1 until 2015.

#### **4.2.1.5 *Uncertainties and time-series consistency***

Uncertainty estimates for greenhouse gases are given in Annex II.

The two plants have reported their emissions to the Norwegian Environment Agency for many years. Cement production was included in the EU ETS in 2005. After entering the EU ETS, the plants faced stricter requirements concerning how AD and EF are determined and the EFs vary more from one year to another. The reduction in IEF from 2009 to 2010 is a consequence of lower EFs in 2010 for both plants. The EF for the plant producing about 70% of the total production decreased the most, pushing the IEF for total production down. This explains the inter-annual variations in the IEF in the end of the time series.

#### **4.2.1.6 *Category-specific QA/QC and verification***

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the Norwegian Environment Agency's inventory team.

Statistics Norway occasionally calculates alternative emission figures for CO<sub>2</sub> and compares them with the emission figures reported by the plants to the Norwegian Environment Agency to check if they are reasonable. The calculations are based on the clinker production (reported annually from the plants to the Statistic Norway). The calculated emission figures have agreed quite well with emissions figures reported by the plants.

#### **4.2.1.7 *Category-specific recalculations***

There have been no recalculations performed for this source category this year.

#### **4.2.1.8 *Category-specific planned improvements***

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 4.2.2 Lime Production, 2A2 (Key category for CO<sub>2</sub>)

### 4.2.2.1 Category description

Three plants that produce lime in Norway reported CO<sub>2</sub> emissions from processes to the Norwegian Environment Agency and all three plants are covered by the EU ETS. The large increase in CO<sub>2</sub> emissions from lime production from 1990 is due to increased production at existing plants and the establishment of a new plant in 2007 with large production. CO<sub>2</sub> from lime production is defined as a key category according to the approach 1 analysis.

### 4.2.2.2 Methodological issues

All three plants calculate the emissions of CO<sub>2</sub> based on the input of limestone and dolomite and plant specific emission factors for CO<sub>2</sub> from limestone and dolomite respectively. The emissions are reported to the Norwegian Environment Agency in accordance with the reporting requirements of the EU ETS<sup>12</sup> and is in line with the tier 3 method of the IPCC 2006 GL. The activity data is corrected for lime kiln dust (LKD).

### 4.2.2.3 Activity data

The activity data used for the reported emissions is the input of limestone and dolomite and this is reported annually to the Norwegian Environment Agency. Nearly all production in Norway consists of quicklime, but there is also some dolomitic lime. Table 4.8 shows the lime production and consumption in 2A for some of the years in the time series.

**Table 4.8 Input of limestone and dolomite and limestone production (ktonnes) in 2A2.**

| Year | Total limestone and dolomite consumption | Total limestone production |
|------|------------------------------------------|----------------------------|
| 1990 | 116.3                                    | 62.0                       |
| 1995 | 162.7                                    | 86.8                       |
| 2000 | 158.9                                    | 84.6                       |
| 2005 | 197.6                                    | 102.6                      |
| 2010 | 576.5                                    | 315.2                      |
| 2012 | 531.6                                    | 289.0                      |
| 2013 | 518.1                                    | 293.5                      |
| 2014 | 521.5                                    | 295.3                      |
| 2015 | 524.8                                    | 286.1                      |
| 2016 | 519.1                                    | 293.4                      |
| 2017 | 510.8                                    | 282.1                      |
| 2018 | 489.3                                    | 269.2                      |
| 2019 | 475.5                                    | 265.4                      |

<sup>12</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012R0601-20190101&from=EN>

|      |       |       |
|------|-------|-------|
| 2020 | 453.4 | 251.7 |
| 2021 | 488.8 | 272.5 |

*Source: Statistics Norway and the Norwegian Environment Agency*

Even though the emissions are calculated based on limestone and dolomite consumption, Norway reports final lime production values as AD in CRF Table 2(I).A-Hs1 in order to assist with comparability across Parties.

#### **4.2.2.4 Emission factors**

The plants use an emission factor of 0.474 tonnes CO<sub>2</sub> per tonne dolomite used. The emission factors for limestone are plant specific and are in the range of 0.43-0.44 (reported with more decimals). One plant used a conversion factor of 1 until 2007 and the two others until 2008. This means that all Ca and Mg have been assumed to be carbonates. Since then, the plants have reported conversion factors that are less than 1.

#### **4.2.2.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

Figure 4-1 shows the IEFs for lime production for both consumption and production as AD. Using final lime production values as AD results in IEFs closer to the default IPCC EF, but also to less stable IEFs as it varies more than if consumption is used as AD.

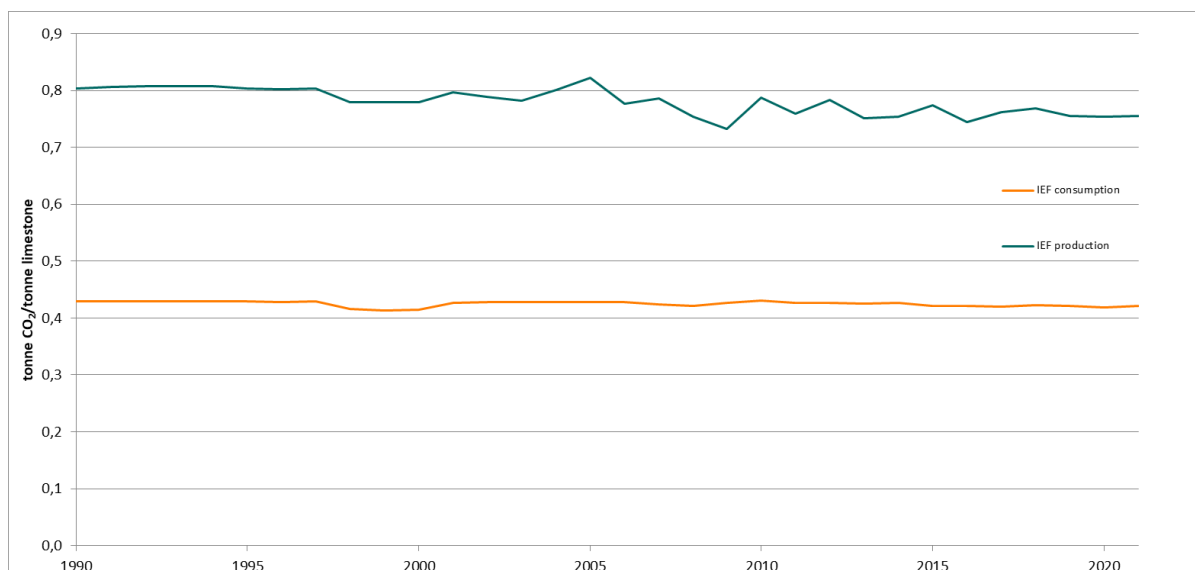


Figure 4-1 IEF (tonne CO<sub>2</sub> per tonne limestone) with consumption or production as AD. Source: Norwegian Environment Agency

#### 4.2.2.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by Norwegian Environment Agency's inventory team.

#### 4.2.2.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

#### 4.2.2.8 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 4.2.3 Glass production, 2A3

#### 4.2.3.1 Category description

Three plants producing glass or glass fibre are included in the emission inventory, based on emission reports to the Norwegian Environment Agency. All three plants are covered by the EU ETS.

#### **4.2.3.2 Methodological issues**

Two plants producing glass wool and one plant producing glass fibre report emission figures on CO<sub>2</sub> to the Norwegian Environment Agency. The two glass wool producing plants report emissions from the use of soda ash, limestone and dolomite, while the glass fibre producer reports emissions from the use of limestone and dolomite.

#### **4.2.3.3 Activity data**

The aggregated use of soda ash, limestone and dolomite is reported as activity data in CRF Table 2(I).A-Hs while details for the use of soda ash and dolomite are shown in [Table 4.9](#) and [Table 4.6](#).

#### **4.2.3.4 Emission factors**

The emission factors used are 0.41492 tonnes CO<sub>2</sub>/tonne soda ash (IPCC 2006), 0.477 tonnes CO<sub>2</sub>/tonne dolomite (EU ETS) and 0.44 tonnes CO<sub>2</sub>/tonne limestone (EU ETS).

#### **4.2.3.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.2.3.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the Norwegian Environment Agency's inventory team.

#### **4.2.3.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.2.3.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.2.4 Ceramics, 2A4a**

#### **4.2.4.1 Category description**

One plant that produced bricks until 2014 is included in the emission inventory, based on emission reported to the Norwegian Environment Agency. The plant was covered by the EU ETS.

#### **4.2.4.2 Methodological issues**

The plant reported emission figures of CO<sub>2</sub> to the Norwegian Environment Agency. The emissions are calculated by multiplying the amount of limestone and clay used in its production with emission factors.

#### **4.2.4.3 Activity data**

The amount of limestone and clay used in the production of bricks was reported each year from the plant to the Norwegian Environment Agency. The amounts of limestone used are reported in CRF Table 2(I).A-Hs1.

#### **4.2.4.4 Emission factors**

The EF of 0.44 tonnes CO<sub>2</sub> per tonne limestone used by the brick producing plant is the standard EF used in the EU ETS for limestone. The plant used an emission factor of 0.088 tonnes CO<sub>2</sub> per tonne clay used.

#### **4.2.4.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

The emissions reported under 2A4a include emissions from the use of clay, but the AD in the CRF is limestone only. The use of clay has decreased since 1996 and this explains the overall decrease in IEF for 2A4a. Calculations show that the IEF for CO<sub>2</sub> from limestone and dolomite use only is more stable than when the emissions from the use of clay also are included.

#### **4.2.4.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions were covered by the EU ETS and their emissions were verified annually. In addition, the emissions were checked both by the case handler and by the Norwegian Environment Agency's inventory team.

#### **4.2.4.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.2.4.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.



## 4.2.5 Other uses of soda ash, 2A4b

### 4.2.5.1 Category description

There is no production of soda ash in Norway, so all soda ash is imported. Soda ash is used and reported in 2A3 (glassworks), 2C3 (aluminium production) and 2C7a<sub>ii</sub> (nickel production). The import of soda ash is higher than the sum of the amounts consumed in these industries. This difference is assumed to be emissive, and the corresponding CO<sub>2</sub>-emissions are estimated and reported here under 2A4b.

### 4.2.5.2 Methodological issues

The emission figures for CO<sub>2</sub> are estimated by multiplying the amount of soda ash assumed to be emissive with an emission factor.

### 4.2.5.3 Activity data

The activity data is total import of soda ash minus consumption in glass wool, nickel and aluminium production. The amounts of soda ash are reported in CRF Table 2(I).A-Hs1 and are shown in Table 4.9.

| Table 4.9 Balance for soda ash use for Norway (ktonnes). |        |                                     |                     |                                  |                                 |
|----------------------------------------------------------|--------|-------------------------------------|---------------------|----------------------------------|---------------------------------|
| Year                                                     | Import | 2A4b<br>(Other uses of<br>soda ash) | 2A3<br>(Glassworks) | 2C3<br>(Aluminium<br>production) | 2C7ii<br>(Nickel<br>production) |
| 1990                                                     | 45.1   | 21.7                                | 4.2                 | 0.9                              | 18.3                            |
| 1995                                                     | 55.0   | 24.5                                | 4.2                 | 0.9                              | 25.3                            |
| 2000                                                     | 49.1   | 17.0                                | 5.3                 | 0.9                              | 25.8                            |
| 2005                                                     | 63.8   | 21.3                                | 5.4                 | 0.9                              | 36.1                            |
| 2010                                                     | 34.9   | 0.0                                 | 3.5                 | 0.9                              | 33.6                            |
| 2012                                                     | 42.1   | 0.0                                 | 3.7                 | 0.9                              | 38.1                            |
| 2013                                                     | 51.8   | 11.1                                | 4.0                 | 0.9                              | 35.8                            |
| 2014                                                     | 47.5   | 5.1                                 | 3.4                 | 1.1                              | 37.8                            |
| 2015                                                     | 44.1   | 2.6                                 | 4.0                 | 1.2                              | 36.2                            |
| 2016                                                     | 47.8   | 7.2                                 | 3.7                 | 0.9                              | 36.0                            |
| 2017                                                     | 47.5   | 8.1                                 | 3.7                 | 0.7                              | 34.9                            |
| 2018                                                     | 47.2   | 4.0                                 | 3.7                 | 0.9                              | 38.6                            |
| 2019                                                     | 54.5   | 12.9                                | 3.6                 | 0.9                              | 37.1                            |
| 2020                                                     | 43.8   | 4.7                                 | 3.8                 | 0.8                              | 34.5                            |
| 2021                                                     | 52.6   | 10.6                                | 3.2                 | 1.1                              | 37.6                            |

#### **4.2.5.4 Emission factors**

The emission factor for soda ash use is 0.41492 tonnes CO<sub>2</sub>/tonne soda ash from the IPCC 2006 Guidelines (IPCC 2006).

#### **4.2.5.5 Uncertainties and time-series consistency**

The estimated and reported emissions under 2A4b are determined by deducting known use in 2A3, 2C3 and 2C7ii from the import of soda ash. As we do not have sufficient information to determine where the rest of the imported soda ash has been consumed, there is some uncertainty as to whether all soda ash consumption in fact is emissive. There is also some uncertainty associated with the foreign trade statistics, as well as with the assumption that the CO<sub>2</sub> is emitted the same year as the soda ash are imported. According to the IPCC 2006 Guidelines, there is negligible uncertainty associated with the emission factor, given that the correct emission factor is applied (IPCC 2006).

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.2.5.6 Category-specific QA/QC and verification**

There is no source specific QA/QC procedure for this sector. However, when the calculation first was included in the inventory, a comparison was made between figures on net import of soda ash in foreign trade statistics and in the Norwegian Product Register. Import figures from the Product Register for the period 2000-2011 never constituted more than 41% of the amounts imported according to foreign trade statistics. Thus, it was assumed that the net import in the foreign trade statistics is a good proxy for the total quantity of soda ash used in Norway.

#### **4.2.5.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.2.5.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category. In the future, we might examine what these other uses of soda ash actually are in order to confirm whether they are emissive or not.

### **4.2.6 Non-metallurgical magnesium production, 2A4c**

#### **4.2.6.1 Category description**

One plant whose main activity is producing magnesium oxide from limestone and dolomite is included in the emission inventory. The plant was established in 2005 and is covered by the EU ETS.

#### 4.2.6.2 Methodological issues

The plant reports emission figures of CO<sub>2</sub> to the Norwegian Environment Agency. The emissions are calculated by multiplying the amount of limestone and dolomite used in its production with emission factors.

#### 4.2.6.3 Activity data

The amount of limestone and dolomite used in the production is reported each year from the plant to the Norwegian Environment Agency. The aggregate amounts of limestone and dolomite used are reported in CRF Table 2(l).A-Hs1 and [Table 4.10](#) shows the usage for some selected years in the time series.

| Year | Limestone use | Dolomite use |
|------|---------------|--------------|
| 2005 | 0.0           | 1.4          |
| 2010 | 1.4           | 0.0          |
| 2012 | 0.0           | 14.2         |
| 2013 | 0.0           | 124.5        |
| 2014 | 0.0           | 163.7        |
| 2015 | 0.0           | 147.3        |
| 2016 | 0.0           | 90.2         |
| 2017 | 0.0           | 32.5         |
| 2018 | 0.0           | 66.6         |
| 2019 | 0.0           | 109.1        |
| 2020 | 0.0           | 50.2         |
| 2021 | 0.0           | 6.6          |

Source: Norwegian Environment Agency

#### 4.2.6.4 Emission factors

The plant has used the emission factor (EF) equal to the standard EF used in the EU ETS for limestone before it entered the EU ETS and uses plant specific EFs after it has entered the EU ETS. The plant does not use limestone every year, and the EFs for 2006, 2008, 2009 and 2010 are in the range of 0.41-0.4504. The EF for the dolomite used is equal to the standard EF used in the EU ETS (0.45) for 2005, 2006 and 2007 before it entered the EU ETS. From 2008 the plant has used plant specific EFs in the range of 0.40940014-0.495096639. With the exception of 2012 and 2015-2018, the plant has used a conversion factor of 1. This means that for most years, all Ca and Mg have been assumed to be carbonates.

#### **4.2.6.5 *Uncertainties and time-series consistency***

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.2.6.6 *Category-specific QA/QC and verification***

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the Norwegian Environment Agency's inventory team.

#### **4.2.6.7 *Category-specific recalculations***

There have been no recalculations performed for this source category this year.

#### **4.2.6.8 *Category-specific planned improvements***

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.2.7 *Other process use of carbonates, 2A4d***

#### **4.2.7.1 *Category description***

The emissions from five plants are reported here under 2A4d. The CO<sub>2</sub> emissions from two plants producing leca are included in the emission inventory, based on emission reports to the Norwegian Environment Agency. One of the plants stopped its production in 2004 and the existing plant is covered by the EU ETS. The third plant has neutralized sulphuric acid waste primarily with limestone and fly ash but uses now only fly ash. The use of fly ash reduces the CO<sub>2</sub> emissions compared with when limestone is used. Finally, the category includes CO<sub>2</sub> emissions from two plants producing rock wool, based on emission reports to the Norwegian Environment Agency.

#### **4.2.7.2 *Methodological issues***

The two plants producing leca report their use of dolomite and the corresponding CO<sub>2</sub> emissions to the Norwegian Environment Agency. The leca producer that still is in production also reports some minor emissions from the use of clay and these are included in the inventory. For the plant neutralizing sulphuric acid waste, the emissions are calculated by multiplying the amounts of limestone and fly ash used to neutralize sulphuric acid waste with emission factors. Data for the amounts of fly ash are only reported for 1997-2016. In addition, the plant has reported emissions from the use of fly ash only for 2010 and later years. For 1997-2009, CO<sub>2</sub> emissions from fly ash use have therefore been

estimated and for 2017 and later years the amounts of fly ash have been estimated. The two plants producing rock wool report their use of dolomite and limestone and the corresponding CO<sub>2</sub> emissions to the Norwegian Environment Agency.

#### 4.2.7.3 Activity data

The activity data are primarily the use of dolomite and limestone, but there is also some use of clay and fly ash. The aggregate amounts of limestone and dolomite used by the plants included in 2A4d are reported in the CRF Table 2(I).A-Hs1. [Table 4.11](#) shows the various activity data for some selected years in the time series.

| <b>Table 4.11 Use of limestone, dolomite, clay and fly ash in 2A4d (other process use of carbonates), all in kt.</b> |           |          |       |         |
|----------------------------------------------------------------------------------------------------------------------|-----------|----------|-------|---------|
| Year                                                                                                                 | Limestone | Dolomite | Clay  | Fly ash |
| 2010                                                                                                                 | 0.0       | 8.7      | 174.0 | 118.3   |
| 2011                                                                                                                 | 33.2      | 14.4     | 171.4 | 122.8   |
| 2012                                                                                                                 | 5.9       | 18.9     | 175.8 | 129.8   |
| 2013                                                                                                                 | 33.9      | 17.7     | 155.5 | 128.5   |
| 2014                                                                                                                 | 0.0       | 16.3     | 135.0 | 129.9   |
| 2015                                                                                                                 | 0.0       | 15.3     | 99.5  | 132.6   |
| 2016                                                                                                                 | 0.0       | 11.5     | 133.2 | 145.2   |
| 2017                                                                                                                 | 0.0       | 15.6     | 147.9 | 152.5   |
| 2018                                                                                                                 | 0.0       | 17.4     | 154.2 | 127.6   |
| 2019                                                                                                                 | 0.0       | 10.1     | 154.7 | 98.3    |
| 2020                                                                                                                 | 0.0       | 12.6     | 112.0 | 112.9   |
| 2021                                                                                                                 | 0.0       | 18.3     | 145.3 | 51.3    |

Source: Norwegian Environment Agency

#### 4.2.7.4 Emission factors

An emission factor (EF) of 0.48 t CO<sub>2</sub>/t dolomite was used by the leca producer that closed in 2004. At that time, there was no standard EF for dolomite. We assume that the EF of 0.48 is derived from the standard factors for CaCO<sub>3</sub> and MgCO<sub>3</sub> and an assumption of the ratio of these in the dolomite. For the leca producer that still is in production, the EF (for dolomite) for 1990-2011 is 0.477 and has since then used standard EF from the EU ETS and plant specific EFs in the range of 0.466-0.48. The EFs for the use of clay from 2013 and onwards ranges between 0.01596492-0.01974294. The plant that neutralizes sulphuric acid waste uses an emission factor of 0.44 t CO<sub>2</sub>/t limestone. For fly ash, IEFs for the years 2010-2016 have been calculated by the Norwegian Environment Agency to be in the range of 40 to 140.2 kg CO<sub>2</sub>/t fly ash and with an average of 72.7 based on activity data and emissions.

The IEF of 68.5 kg CO<sub>2</sub>/t fly ash for 2010 (closest year with reported data) has been used for the years 1997-2009 and the IEF of 68.2 kg CO<sub>2</sub>/t fly ash for 2016 (closest year with reported data) has been used for the years after 2016. The two plants producing rock wool use emission factors of 0.44 t CO<sub>2</sub>/t limestone and 0.481 t CO<sub>2</sub>/t dolomite.

#### **4.2.7.5 *Uncertainties and time-series consistency***

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category. The IEF is relatively stable 1990-2008, variations may be due to emissions from the use of clay and ash that are not included as AD in the CRF. The IEF since 2008 varies more and this is primarily due to a shift from using limestone to ash at the plant that neutralizes sulphuric acid waste.

#### **4.2.7.6 *Category-specific QA/QC and verification***

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The existing plant producing leca is covered by the EU ETS and the emissions are verified annually. The emissions are checked both by the case handler and by the Norwegian Environment Agency's inventory team. The reported emissions from the plant that neutralizes sulphuric acid waste occurs under its regular permit and are checked both by the case handler and by the agency's inventory team.

#### **4.2.7.7 *Category-specific recalculations***

There have been no recalculations performed for this source category this year.

#### **4.2.7.8 *Category-specific planned improvements***

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 4.3 Chemical industry – 2B

Several activities are included under Chemical Industry. Nearly all emissions figures from this industry included in the inventory are reported figures from the plants to the Norwegian Environment Agency. Table 4.12 shows the GHGs that are emitted from each source category, tier of methodology and if the source category is key category or not.

**Table 4.12 Chemical industry. Components included in the inventory, tier of method and key category.**

| Source category                  | CO <sub>2</sub> | CH <sub>4</sub> | N <sub>2</sub> O | NM VOC | Tier   | Key category |
|----------------------------------|-----------------|-----------------|------------------|--------|--------|--------------|
| 2B1. Ammonia production          | R               | NA              | NA               | NA     | Tier 2 | Yes          |
| 2B2. Nitric acid production      | NA              | NA              | R                | NA     | Tier 3 | Yes          |
| 2B5a. Silicon carbide production | R+E             | R/E             | NA               | NA     | Tier 2 | Yes          |
| 2B5b. Calcium carbide production | R               | NA              | NA               | R      | Tier 1 | No*          |
| 2B6. Titanium dioxide production | R               | NA              | NA               | NA     | Tier 2 | Yes          |
| 2B8a. Methanol production **     | R               | R+E             | R                | R+E    | Tier 2 | Yes***       |
| 2B8b. Ethylene production **     | R+E             | R               | R                | R      | Tier 2 | Yes***       |
| 2B8g. Other                      | R+E             | R               | NA               | R      | Tier 2 | Yes***       |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occurring. IE = Included Elsewhere.*

*\* In the key category analysis, 2B5a and 2B5b have been aggregated to 2B5.*

*\*Minor N<sub>2</sub>O emissions from 2B8a and 2B8b are reported under 2B10 Petrochemical N<sub>2</sub>O in the CRF*

*\*\* In the key category analysis, 2B8a, 2B8b and 2B8g have been aggregated to 2B8*

Table 4.13 shows the trends for 2B as a whole and for the various source categories. The GHG emissions from this sector category were about 1.8 million tonnes in 2021, this is 20.4% of the total emission from the IPPU sector. The emissions from this sector decreased by 52.8% from 1990, mainly due to lower emissions from the production of nitric acid, ammonia and carbide. The emissions decreased by 7.5% from 2020 to 2021.

| <b>Table 4.13 Emission trends for 2B Chemical industry (t CO<sub>2</sub> equivalents).</b> |           |                       |           |           |                       |                               |                               |
|--------------------------------------------------------------------------------------------|-----------|-----------------------|-----------|-----------|-----------------------|-------------------------------|-------------------------------|
| Source category                                                                            | 1990      | 1990,<br>% of<br>IPPU | 2020      | 2021      | 2021,<br>% of<br>IPPU | Trend<br>1990-<br>2021<br>(%) | Trend<br>2020-<br>2021<br>(%) |
| 2B1. Ammonia production                                                                    | 795 193   | 5.4                   | 625 894   | 543 571   | 6.0                   | -31.6                         | -13.2                         |
| 2B2. Nitric acid production                                                                | 1 772 585 | 12.1                  | 88 217    | 48 907    | 0.5                   | -97.2                         | -44.6                         |
| 2B5a. Silicon carbide production                                                           | 245 624   | 1.7                   | 48 704    | 48 252    | 0.5                   | -80.4                         | -0.9                          |
| 2B5b. Calcium carbide production                                                           | 178 128   | 1.2                   | 0         | 0         | 0.0                   | -100.0                        | NA                            |
| 2B6. Titanium dioxide production                                                           | 201 100   | 1.4                   | 271 814   | 275 645   | 3.1                   | 37.1                          | 1.4                           |
| 2B8a. Methanol production                                                                  | 0         | 0.0                   | 281 563   | 231 060   | 2.6                   | NA                            | -17.9                         |
| 2B8b. Ethylene production                                                                  | 606 909   | 4.1                   | 556 983   | 547 356   | 6.1                   | -9.8                          | -1.7                          |
| 2B8g. Other                                                                                | 47 845    | 0.3                   | 16 900    | 19 624    | 0.2                   | -59.0                         | 16.1                          |
| 2B10. Petrochemical N <sub>2</sub> O                                                       | 158       | 0.0                   | 378       | 378       | 0.0                   | 139.3                         | 0.1                           |
| 2B10. Other (production of fertilizers)                                                    | 51 539    | 0.4                   | 98 580    | 124 550   | 1.4                   | 141.7                         | 26.3                          |
| 2B. Total                                                                                  | 3 899 081 | 26.5                  | 1 989 032 | 1 839 342 | 20.4                  | -52.8                         | -7.5                          |

Source: Statistics Norway and the Norwegian Environment Agency

### 4.3.1 Ammonia Production, 2B1 (Key category for CO<sub>2</sub>)

#### 4.3.1.1 Category description

In Norway ammonia is produced by catalytic steam reforming of wet fuel gas (containing ethane, propane, and some butane). This is one of the steps in the production of fertilizers. Hydrogen is needed to produce ammonia, and wet fuel gas is the basis for the production of hydrogen. The emissions reported in this category includes all emissions from combustion of fuels and includes emissions from heavy heating oil used in boiler and from ethane used for direct heating. A substantial amount of CO<sub>2</sub> is recovered from the production process.

CO<sub>2</sub> from ammonia production is defined as a key category according to the approach 1 analysis.

Figure 4-2 shows the time series for the gross CO<sub>2</sub> emissions, amount of recovered CO<sub>2</sub> and the net CO<sub>2</sub> emissions reported in 2B1. The variations from 1998 to 1999 and 1999 to 2000 are likely to be a result of the plant upgrading production capacity and energy efficiency in



1999-2000. The increase in emissions from 2014 to 2015 is due to an expansion in production capacity in which imported ammonia is replaced with domestic ammonia production. The emissions decreased however in 2016 and 2017 since domestic ammonia production decreased. In 2018, the emissions increased as domestic ammonia production increased.

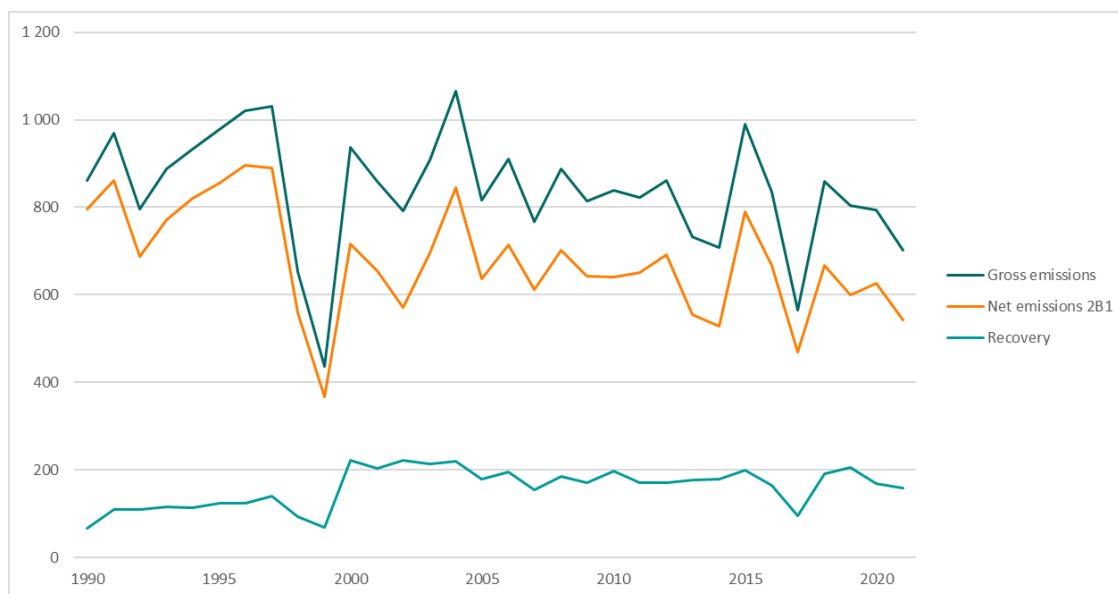


Figure 4-2 CO<sub>2</sub> emissions from production of ammonia. Source: Norwegian Environment Agency

#### 4.3.1.2 Methodological issues

The CO<sub>2</sub> emission figures in the Norwegian emission inventory are based on annual reports from the plant that is included in the EU ETS. The plant has reported consistent figures back to 1990 and calculates the emissions by multiplying the used amount of each fossil fuel with emission factors. Statistics Norway allocates these emissions to IPPU and ensures that emissions from this fuel use are not also reported under Energy.

The gross emissions include captured CO<sub>2</sub>. A part of the CO<sub>2</sub>, which is generated during the production process, is captured, and sold to other objectives et cetera soft drinks, and therefore deducted from the emission figures for this source. The amount of CO<sub>2</sub> recovered by the plant is determined by using the amount of CO<sub>2</sub> from the compressor unit minus the amount of CO<sub>2</sub> emitted. In both cases, these are measured by orifice plate with a dp-cell. This then goes to tank and then transported by trucks or boats. In accordance with the footnote 5 in CRF table 2(I)A-H, the amount of CO<sub>2</sub> reported as recovered that is not exported is included in 2H2 Food and Drink.

Subtracting the captured CO<sub>2</sub> results in the net emissions reported in 2B1. [Table 4.14](#) below presents the various activity data, emission factors, emissions, and the balance between gross, captured CO<sub>2</sub> and reported emissions in 2B1.

| <b>Table 4.14 Activity data, emission factors and balance for 2B1 in 2021.</b> |         |                                                   |                         |
|--------------------------------------------------------------------------------|---------|---------------------------------------------------|-------------------------|
|                                                                                | ktonnes | Emission factor<br>(tonne CO <sub>2</sub> /tonne) | ktonnes CO <sub>2</sub> |
| Heating oil                                                                    | 1.2     | 3.17                                              | 3.7                     |
| Liquified petroleum gas                                                        | 13.8    | 2.995046431                                       | 41.5                    |
| CO-rich gas                                                                    | 0.0     | -                                                 | 0.0                     |
| Ethane                                                                         | 224.4   | 2.927302482                                       | 656.9                   |
| Gross emissions                                                                |         |                                                   | 702.1                   |
| Captured CO <sub>2</sub>                                                       |         |                                                   | 158.6                   |
| Net emissions in 2B1                                                           |         |                                                   | 543.6                   |

Source: Norwegian Environment Agency

#### **4.3.1.3 Activity data**

The total amount of fossil fuels used are reported annually by the plant to the Norwegian Environment Agency and the use varies from one year to another. The various fuels used in the latest reported year are shown in [Table 4.14](#). As a part of the official Industrial statistics, gas consumed is also reported to Statistics Norway that uses these figures for the QA/QC calculations by an alternative method. The ammonia production is reported in CRF Table2(I).A-Hs1.

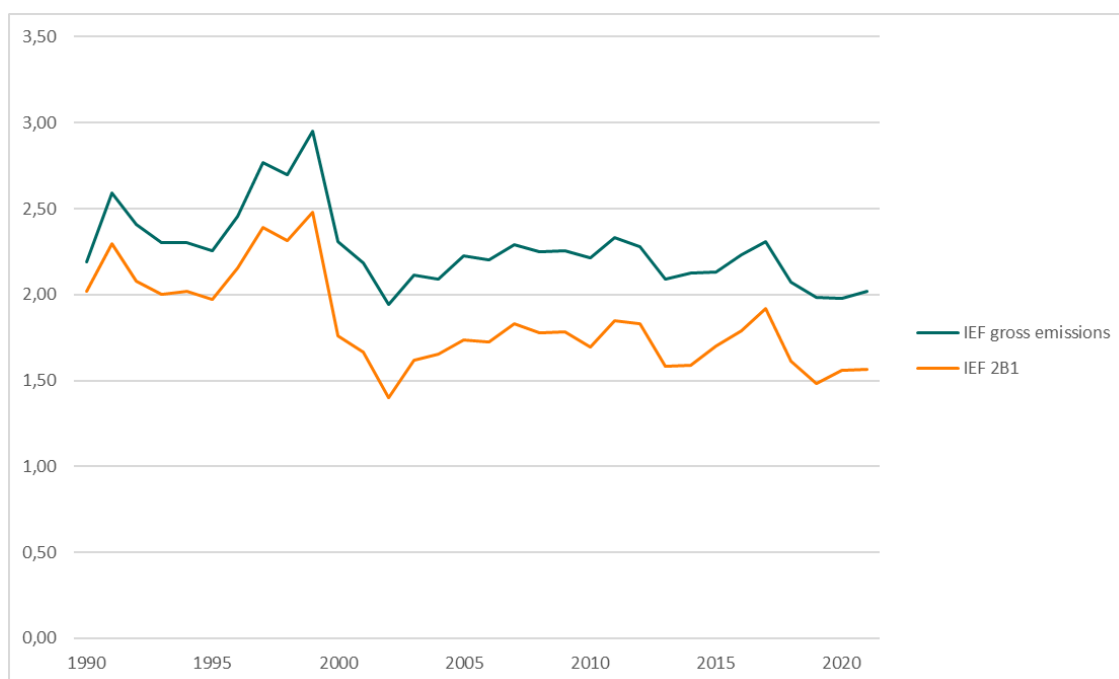
#### **4.3.1.4 Emission factors**

The emission factors used are estimated based on the composition of the gases consumed. The plant states that the composition is based on daily analysis and that the composition of each gas (their emission factor) is stable. The reported emission factors for the latest reported year are shown in [Table 4.14](#).

#### **4.3.1.5 Uncertainties and time-series consistency**

The amount of gas is measured by using turbine meters and the meters are controlled by the Norwegian Metrology Service. The uncertainty in the measurement of propane and butanes is calculated to  $\pm 0.2$  and ethane  $\pm 0.13\%$ . The mix of propane/butanes is as average 60% propane and 40% butanes.

Figure 4-3 shows that there are some inter-annual variations in the IEF. The variations from 1998 to 1999 and 1999 to 2000 are likely to be a result of the plant upgrading production capacity and energy efficiency in 1999-2000. *Figure 4-2* shows that there was a large drop in emissions and recovery in 1999. It is challenging to investigate this further as more data is not available and since the data quality at that time is poorer than now. Since the plant has reported under the voluntary agreement for 2008-2012 and under the EU ETS from 2013, the data quality has improved and the IEF is relatively stable in the end of the time series.



*Figure 4-3 IEF for process emissions of CO<sub>2</sub> from ammonia production (tonne CO<sub>2</sub>/tonne ammonia). Source: Norwegian Environment Agency*

#### 4.3.1.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plant has reported under the voluntary agreement and the emissions are now covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

The figures reported from the plant are occasionally compared to calculations done by Statistics Norway based on total amount of gas consumed and an emission factor of 3

tonne CO<sub>2</sub>/tonne LPG. The calculated emissions figures have agreed quite well with emissions figures reported by the enterprise.

#### **4.3.1.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.3.1.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.3.2 Production of Nitric Acid, 2B2 (Key category for N<sub>2</sub>O)**

#### **4.3.2.1 Category description**

There are two plants in Norway producing nitric acid and these plants are covered by the EU ETS. Nitric acid is used as a raw material in the manufacture of nitrogenous-based fertilizer. The production of nitric acid (HNO<sub>3</sub>) generates nitrous oxide (N<sub>2</sub>O) and NO<sub>x</sub> as by-products of high temperature catalytic oxidation of ammonia (NH<sub>3</sub>). N<sub>2</sub>O from nitric acid production is defined as a key category according to the approach 2 analysis.

The two plants have together six production lines. One production line was rebuilt in 1991 and in 2006 two lines were equipped with the technology – N<sub>2</sub>O decomposition by extension of the reactor chamber. Since then, all production lines have to a certain extent been equipped with this technology. The newest production line was established in 2018.

Figure 4-4 shows that the production specific N<sub>2</sub>O emissions were reduced substantially in the early 1990s and again from 2006. The reduced emissions in the early 1990s were due to rebuilding of one production line in 1991 and that a larger part of the production came from that line. The reduced emissions from 2006 are due to the installation of the earlier mentioned technology. There was a large increase in production of about 43 percent from 2009 to 2010 that came after a decrease in production of about 26 percent from 2008 to 2009. The low production level in 2009 reflects the lower economic activity due to the economic recession.

#### **4.3.2.2 Methodological issues**

N<sub>2</sub>O

The two plants report the emissions of N<sub>2</sub>O to the agency. The N<sub>2</sub>O emissions have been continuously measured since 1991 at one production line and from 2000 at another. The

emissions at the three other production lines were based on monthly and weekly measurements but are from 2008 based on continuous measurements.<sup>13</sup>

#### 4.3.2.3 Activity data

The plants report the amounts of N<sub>2</sub>O in the gas, based on continuous measurements. The plants also report the production of HNO<sub>3</sub> to the agency. The production and emission levels are shown for some years in Table 4.15.

| <b>Table 4.15 Production (ktonnes HNO<sub>3</sub>) and N<sub>2</sub>O emissions (ktonnes).</b> |                  |                 |
|------------------------------------------------------------------------------------------------|------------------|-----------------|
| Year                                                                                           | Total production | Total emissions |
| 2015                                                                                           | 1 729.7          | 0.844           |
| 2016                                                                                           | 1 669.2          | 0.810           |
| 2017                                                                                           | 1 733.7          | 0.706           |
| 2018                                                                                           | 1 980.6          | 0.669           |
| 2019                                                                                           | 1 916.5          | 0.618           |
| 2020                                                                                           | 1 951.3          | 0.333           |
| 2021                                                                                           | 2 022.1          | 0.185           |

Source: Statistics Norway and Norwegian Environment Agency

#### 4.3.2.4 Emission factors

Not relevant.

#### 4.3.2.5 Uncertainties and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex II. The uncertainty in the measurements was in 2000 estimated by the plant to  $\pm 7\%$ . However, in the 2006 report to the Norwegian Environment Agency one plant reports that the uncertainty in measurement of N<sub>2</sub>O is calculated to  $\pm 1-3\%$ .

The inter-annual changes of IEFs are likely to be explained by variations in the level of production between the lines with different IEFs.

Figure 4-4 shows that the IEF for nitric acid production has been substantially decreased from 1990. The low production level in 2009 reflects the lower economic activity due to the economic recession.

<sup>13</sup> See point 16 in Annex IV of <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012R0601-20190101&from=EN> for the requirements for continuous measurements under the EU ETS.

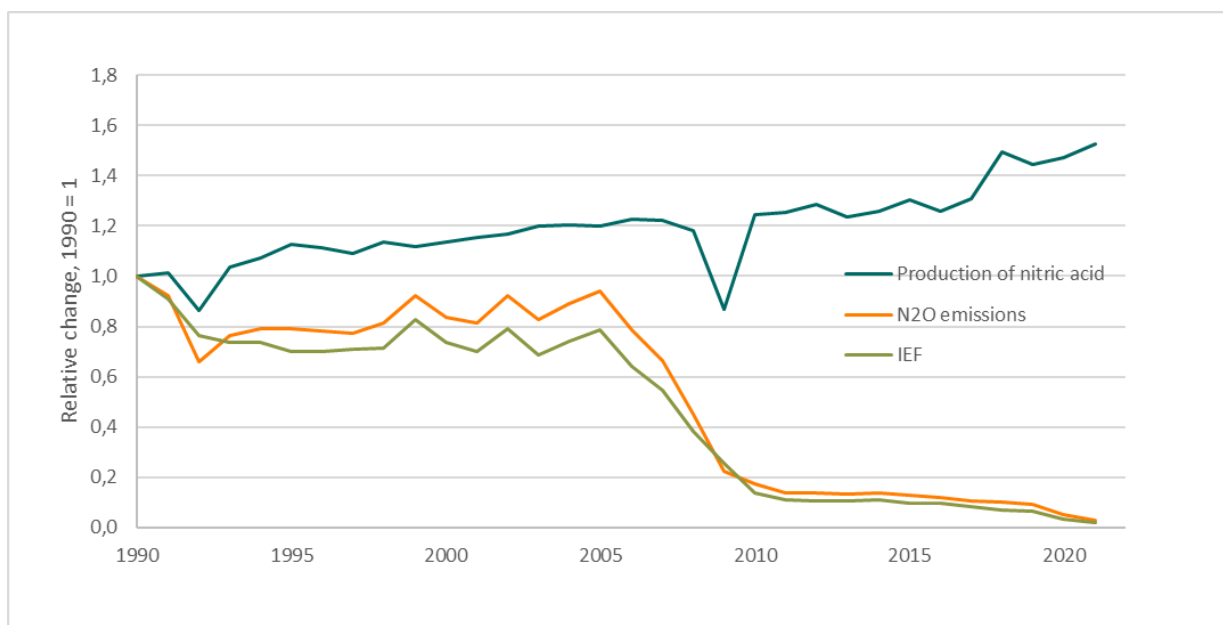


Figure 4-4 Relative change in total emissions, total production and IEF for nitric acid production. 1990=1. Source: Norwegian Environment Agency

#### 4.3.2.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### 4.3.2.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

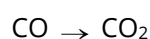
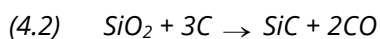
#### 4.3.2.8 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 4.3.3 Silicon carbide, 2B5a (Key category for CO<sub>2</sub>)

#### 4.3.3.1 Category description

Silicon carbide (SiC) has been produced at three plants until 2006 when one plant was closed down. The plants were included into the EU ETS from 2013. SiC is produced by reduction of quartz (SiO<sub>2</sub>) with petrol coke as a reducing agent.



In the production of silicon carbide, CO<sub>2</sub> and CO is released as a by-product from the reaction between quartz and carbon. Methane (CH<sub>4</sub>) may be emitted from petrol coke during parts of the process and sulphur origin from the petrol coke.

The large decrease in emissions since 1990 is due to reduced production and that one plant was closed in 2006. The fluctuation in emissions over the years is due to variation in production of crude silicon carbide. There was a large production decrease from 2002 to 2003 and an increase from 2009 to 2010 and this is due to a low production level in 2009. The production level in 2009 is also lower than 2008 and reflects the lower economic activity due to the economic recession.

CO<sub>2</sub> from carbide production is defined as a key category according to the approach 2 analysis.

#### **4.3.3.2 Methodological issues**

The emissions are calculated based on crude silicon carbide production as activity data and emission factors. This is regarded as being a Tier 2 method in IPCC (2006).

##### CO<sub>2</sub>

Emission figures are reported annually by the three plants to the agency.

CO<sub>2</sub> from process is calculated based on the following equation:

$$(4.3) \quad \text{CO}_2 = \sum \text{Activity data} * \text{Emission factor}$$

The three production sites have used amount of produced crude silicon carbide as activity data in the calculation of CO<sub>2</sub> emissions.

##### NMVOC

Emission figures are reported to the Norwegian Environment Agency by the plants. The emissions are calculated by multiplying annual production of crude silicon carbide by an emission factor.

##### CH<sub>4</sub>

The emission of CH<sub>4</sub> from production of silicon carbide is calculated based on the following equation:

$$(4.4) \quad \text{CH}_4 = \sum \text{Activity data}_i * \text{Emission factor}_i$$

The three production sites have used amount of produced crude silicon carbide as activity data and a plant specific emission factor.

Indirect emissions of CO<sub>2</sub> are reported in CRF table 6 and are calculated by Statistics Norway based on the emission of CH<sub>4</sub> and NMVOC.

#### 4.3.3.3 Activity data

The activity data used by the plants for the calculation of CO<sub>2</sub>, CH<sub>4</sub> and NMVOC are the amount of produced crude silicon carbide. The production is shown in Table 4.16 for some years.

| Table 4.16 Norwegian crude silicon carbide production (ktonnes). |            |
|------------------------------------------------------------------|------------|
| Year                                                             | Production |
| 1990                                                             | 83.4       |
| 1995                                                             | 83.6       |
| 2000                                                             | 66.7       |
| 2005                                                             | 35.0       |
| 2010                                                             | 27.2       |
| 2012                                                             | 15.8       |
| 2013                                                             | 16.9       |
| 2014                                                             | 17.9       |
| 2015                                                             | 17.6       |
| 2016                                                             | 18.7       |
| 2017                                                             | 21.2       |
| 2018                                                             | 21.7       |
| 2019                                                             | 18.4       |
| 2020                                                             | 16.5       |
| 2021                                                             | 16.4       |

Source: Statistics Norway and Norwegian Environment Agency

#### 4.3.3.4 Emission factors

The plants use the country-specific emission factor that is the basis for the IPCC (2006) default factor of 2.62 tonne CO<sub>2</sub>/tonne crude silicon carbides, see Table 4.17. However, the smallest existing producer has recently shifted from producing silicon carbide to special production which is not included as activity data in the CRF. The IEF in the CRF Table2(I).A-Hs1 is therefore slightly higher than 2.62. All plants use the default emission factor of 11.6 kg CH<sub>4</sub> /tonnes crude SiC from the IPCC 2006, see Table 4.17.



| <b>Table 4.17 Emission factor for CO<sub>2</sub> and CH<sub>4</sub> used for silicon carbide production.</b> |                                               |           |
|--------------------------------------------------------------------------------------------------------------|-----------------------------------------------|-----------|
| Component                                                                                                    | Emission factor                               | Source    |
| <b>CO<sub>2</sub></b>                                                                                        | 2.62 tonnes CO <sub>2</sub> /tonnes crude SiC | IPCC 2006 |
| <b>CH<sub>4</sub></b>                                                                                        | 11.6 kg CH <sub>4</sub> /tonnes crude SiC     | IPCC 2006 |

From 2007 and onwards the emission factor for NMVOC is based on measurements made once a year. The emission factors for one of the plants is stable at around 10.8 t NMVOC/kt SiC while the emission factor at the other plant is less stable and increasing. The concerned plant has responded that the variations are within the expected variations. For previous years, the emission factor for one of the plants is more or less constant whereas the emission factor for the second plant varies.

#### **4.3.3.5 Uncertainties and time-series consistency**

##### **4.3.3.5.1 CO<sub>2</sub>**

###### Activity data

The three productions sites use the amount of produced crude silicon carbide as activity data. The uncertainty of the activity data is related to the uncertainty of the weighing equipment and is calculated to be  $\pm 3\%$ .

###### Emission factor

The emission factor of 2.62 tonne CO<sub>2</sub>/tonnes SiC has an estimated uncertainty range of – 16% to +7%. This can be explained due to variations in raw materials as well as process variations, and is based on previous development of country specific emissions factors (SINTEF 1998b).

The carbon content in coke is varying, normally from 85 to 92% carbon. The coke is also varying in the content of volatile components, e.g., hydrocarbons. There are also variations in the process itself. The Acheson process is at batch process, and the reactions include many part reactions that differ from batch to batch, because of variations in the mix of quarts and coke, the reactivity of the coke etc. The process variations described above is the reason why the factor presented in tonne CO<sub>2</sub>/tonne coke used is not constant. For one plant, the factor is in the range 1.07-1.27. For the other plant, one also has to consider the closed plant, because the input and output from them are somewhat mixed together. The factor for them is in the range 0.99-1.24. This implies that the output of SiC will have some variation from batch to batch.

Prior to 2006, the emissions were based on a mass-balance method (input of reducing agents). The justification of changing method is that the IEF tonne CO<sub>2</sub> /tonne coke varies over the years due to variation in carbon content in coke and that this variation is larger or in the same order of variation that the production of crude silicon carbide. In addition, there is a relatively large difference in the carbon consumption data in the early 1990s due to the use of purchase data as a proxy for carbon consumption. The silicon carbide production data in the early 1990s especially is considered being more accurate than the coke consumption.

#### Emissions

The total uncertainty of the resulting emissions of CO<sub>2</sub>, based on uncertainties in activity data and emissions factor, is calculated to be in the range of – 20% to + 10%.

#### 4.3.3.5.2 CH<sub>4</sub>

##### Activity data

The three production sites use the amount of produced crude silicon carbide as activity data. The uncertainty of the activity data given as this production figure is calculated to be  $\pm 3\%$ .

##### Emission factor

The uncertainty level is estimated to be  $\pm 30\%$ . To establish the uncertainty level, the following assessments were done:

- The uncertainty in monitoring of concentration is normally  $\pm 5\%$  (expert judgment).
- The uncertainty of monitoring of the amount of gas is within  $\pm 15\%$  (type of monitoring equipment).
- The uncertainty of the production of SiC for each batch is stable and is assessed to be within a level of  $\pm 5\%$ .
- The uncertainties of raw materials and process variation add  $\pm 5\%$ .

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.3.3.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants have reported under the voluntary agreement and the emissions are now covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### 4.3.3.7 Category-specific recalculations

*Reallocation:* Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

#### 4.3.3.8 Category-specific planned improvements

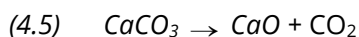
There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 4.3.4 Calcium carbide, 2B5b

#### 4.3.4.1 Category description

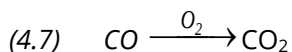
One plant in Norway was producing calcium carbide until 2003 and the emissions from this source were about 178 000 tonnes CO<sub>2</sub> in 1990. The production of calcium carbide generates CO<sub>2</sub> emissions when limestone is heated and when petrol coke is used as a reducing agent.

The reaction



which takes place when limestone (calcium carbonate) is heated.

The reactions



where petrol coke is used as a reducing agent to reduce the CaO to calcium carbide.

#### 4.3.4.2 Methodological issues

The CO<sub>2</sub> figures in the inventory are based on emission figures reported from the plant to the agency. The emission estimates are based on the amount of calcium carbide produced each year and an emission factor estimated by SINTEF (1998b). Some of the carbon from petrol coke will be sequestered in the product, but not permanently. Thus, this carbon is included in the emission estimate.

#### 4.3.4.3 Activity data

The amount of calcium carbide produced is reported by the plant to the agency.

#### 4.3.4.4 Emission factors

The emission factor used by the plants in the calculation of CO<sub>2</sub> has been estimated to be 1.69 tonne/tonne CaC<sub>2</sub> by SINTEF (1998b). An additional 0.02 t CO<sub>2</sub> /t CaC<sub>2</sub> from fuel is reported in the Energy chapter.

#### **4.3.4.5 *Uncertainties and time-series consistency***

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.3.4.6 *Category-specific QA/QC and verification***

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII.

#### **4.3.4.7 *Category specific recalculations***

There have been no recalculations performed for this source category this year.

#### **4.3.4.8 *Category-specific planned improvements***

Since the plant is closed down there is no further planned activity to review historical data.

### **4.3.5 Titanium dioxide production, 2B6 (Key category for CO<sub>2</sub>)**

#### **4.3.5.1 *Category description***

One plant producing titanium dioxide slag is included in the Norwegian inventory and it was included in the EU ETS in 2013. The plant also produced pig iron as a by-product. The titanium dioxide slag and pig iron are produced from the mineral ilmenite and coal is used as a reducing agent. Various components included CO<sub>2</sub> are emitted during the production process.

CO<sub>2</sub> from titanium dioxide production is defined as a key category according to the approach 1 analysis.

#### **4.3.5.2 *Methodological issues***

The method that is used for all years can be defined as a calculation based on carbon balance. This method accounts for all the carbon in the materials entering the process and subtracts the CO<sub>2</sub> captured in the products.

#### **4.3.5.3 *Activity data***

The carbon inputs are dominated by coal, but there is also some pet coke, electrodes, carbides, and some masses. [Table 4.18](#) shows the most important carbon inputs.

| <b>Table 4.18 Carbon inputs (ktonnes) for titanium dioxide production in 2021.</b> |                |
|------------------------------------------------------------------------------------|----------------|
| Activity data                                                                      | Amount (tonne) |
| Coal                                                                               | 92.1           |
| Iron                                                                               | 85.3           |
| Antracites                                                                         | 6.3            |
| Electrode mass (tonne dry weight)                                                  | 1.7            |

Source: Norwegian Environment Agency

#### 4.3.5.4 Emission factors

The mass balance for each year requires emission factors. The emission factors for the most important carbon inputs are shown in Table 4.19.

| <b>Table 4.19 Emission factors for some of the carbon inputs in 2021.</b> |                                   |
|---------------------------------------------------------------------------|-----------------------------------|
| Activity data                                                             | EF (tonne CO <sub>2</sub> /tonne) |
| Coal                                                                      | 2.709964                          |
| Iron                                                                      | 0.151169                          |
| Antracites                                                                | 3.082285                          |
| Electrode mass (tonne dry weight)                                         | 3.478275                          |

Source: Norwegian Environment Agency

#### 4.3.5.5 Uncertainties and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### 4.3.5.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plant has reported under the voluntary agreement and the emissions are now covered by the EU ETS and the emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### 4.3.5.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

#### **4.3.5.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.3.6 Methanol, 2B8a**

#### **4.3.6.1 Category description**

One plant established in 1997 produces methanol and it is covered by the EU ETS. Natural gas and oxygen are used in the production of methanol. The conversion from the raw materials to methanol is done in various steps and on different locations at the plant. CH<sub>4</sub>, N<sub>2</sub>O and NMVOC are emitted during the production process. The emissions reported in this category includes all emissions from flaring and combustion of fuels derived from the natural gas feedstock.

Minor CO<sub>2</sub> emissions from other energy combustion (diesel and propane) are included under 1.A.2.C. Indirect emissions of CO<sub>2</sub> are reported in CRF table 6 and are calculated by Statistics Norway based on the emission of CH<sub>4</sub> and NMVOC, see chapter 9 for details about EFs. Minor N<sub>2</sub>O emissions are reported under 2B10 Petrochemical N<sub>2</sub>O in the CRF.

#### **4.3.6.2 Methodological issues**

The plant reports emission figures of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and NMVOC to the Norwegian Environment Agency. The reported CO<sub>2</sub> emissions from flaring and combustion of derived fuels are based on the amounts of gas multiplied by emission factors and these are all reported under the EU ETS. Statistics Norway allocates these emissions to IPPU and ensures that emissions from this fuel use are not also reported under Energy.

The diffuse CH<sub>4</sub> and NMVOC emissions are estimated through the use of the measuring method DIAL (Differential Absorption LIDAR) about every third year since 2002. The plant was divided into various process areas and measurements were taken for at least two days for all process areas. The DIAL method results in an emission factor per operating hour, and this forms the basis for the plant's reported diffuse NMVOC and CH<sub>4</sub> emissions from the production of methanol. This method has been used from 2008 and onwards. This method therefore results in a fixed emission level for some years. The time series for the years 1997-2007 are based on the results from 2008 together with the production levels of methanol for these years.

The plant has since 2016 revised its method for measuring and reporting fugitive emissions and the change indicates substantially lower emissions. These lower emissions have not yet been reflected into the national inventory as the methods for measuring and reporting

CH<sub>4</sub> emissions are under revision. The reported emissions in the national inventory for 2016 onward are assumed to be the same as for 2013-2015.

#### 4.3.6.3 Activity data

The annual emissions from flaring and combustion of fuels are based on the reported combusted amounts. The total fuels used for some years are shown in Table 4.20. The majority of this is natural gas, but there is also some syngas, flaring gas and liquid off-spec methanol (LOFS). The production volume of methanol in 2021 was about 638 ktonnes and the time series for the production is reported in CRF table2(l).A-Hs1.

**Table 4.20 Sum of fuels (kt) used in methanol production.**

| 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|------|------|------|------|------|
| 159  | 155  | 138  | 125  | 126  | 122  | 101  |

Source: Norwegian Environment Agency

The activity data used to calculate the indirect CO<sub>2</sub> emissions are the diffuse emissions of CH<sub>4</sub> and NMVOC.

#### 4.3.6.4 Emission factors

CO<sub>2</sub>

The plant reports its emission factors to the Norwegian Environment Agency. The EF for natural gas is stable at around 2.70 tonnes CO<sub>2</sub> per tonne natural gas. The EF for the flaring gas varies. The EF for syngas is at around 1.2-1.3 tonnes CO<sub>2</sub> per tonne syngas and the EF for LOFS is around 0.3 tonne CO<sub>2</sub> per tonne LOFS.

#### 4.3.6.5 Uncertainties and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex II.

There are variations in the implied emission factor. This is primarily due to the variations in the level of flaring. The IEF peaks occur in years when the level of flaring is high.

#### 4.3.6.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants emissions are verified annually under the EU ETS. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### 4.3.6.7 Category-specific recalculations

**Reallocation:** Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

#### **4.3.6.8 Category-specific planned improvements**

Once the plant's revised method for measuring and reporting fugitive emissions is finalized, it will be considered for implementation in the national GHG inventory.

### **4.3.7 Ethylene, 2B8b**

#### **4.3.7.1 Category description**

From 1990 until 2000, the emissions reported under this category were from one single plant that produced primarily ethylene, but also vinyl chloride and propylene. In 2001, the part of the plant producing vinyl chloride was separated into a different plant. So, from 2001, the emissions are reported by two plants, and they are now both covered by the EU ETS.

Most of the emissions reported under this category are CO<sub>2</sub> emissions from the production of ethylene, but there are also CO<sub>2</sub> emissions from the production of vinyl chloride and propylene. The emissions in this category include all emissions from the plants with the exception of minor emissions from the combustion of diesel and propane, these are reported under 1A2C. Emissions of CH<sub>4</sub> and NMVOC emissions from leakages in the process are also included. Indirect emissions of CO<sub>2</sub> from CH<sub>4</sub> and NMVOC are reported in CRF table 6. Minor N<sub>2</sub>O emissions are reported under 2B10 Petrochemical N<sub>2</sub>O in the CRF.

#### **4.3.7.2 Methodological issues**

##### CO<sub>2</sub>, CH<sub>4</sub> and NMVOC

The plants report emission figures of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and NMVOC to the Norwegian Environment Agency. For the plant that primarily produces ethylene, the reported emissions from flaring and combustion of fuels are based on the amounts of gas multiplied by emission factors. For the plant producing vinyl chloride, the reported CO<sub>2</sub> emissions stem from recycling hazardous waste to hydrochloric acid.

Statistics Norway allocates these emissions in IPPU and ensures that emissions from this fuel use are not also reported under Energy. The CH<sub>4</sub> and NMVOC emissions are based on measurements and are reported to the Norwegian Environment Agency.

Indirect emissions of CO<sub>2</sub> calculated by Statistics Norway are based on the emission of CH<sub>4</sub> and NMVOC.



#### 4.3.7.3 Activity data

The annual emissions from flaring and combustion of fuels are based on the reported combusted amounts. The total fuels used for some years are shown in Table 4.21. The majority of this is natural gas, but there is also some flaring gas, oxy exhaust gas and hazardous waste. The production volumes of ethylene, VCM, propylene and vinyl chloride are aggregated and reported in CRF table2(I).A-Hs1. The production volumes of ethylene and VCM in 2021 were about 616 ktonnes and 540 ktonnes respectively.

**Table 4.21 Sum of fuels (kt) used in 2B8b.**

| 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|------|------|------|------|------|
| 572  | 522  | 560  | 569  | 529  | 570  | 573  |

Source: Norwegian Environment Agency

The CH<sub>4</sub> and NMVOC emissions are reported annually to the Norwegian Environment Agency. The activity data used to calculate the indirect CO<sub>2</sub> emissions are the diffuse emissions of CH<sub>4</sub> and NMVOC.

#### 4.3.7.4 Emission factors

CO<sub>2</sub>

The plants report the emission factors used as part of their reporting under the EU ETS.

CH<sub>4</sub>

For the plant producing vinyl chloride, the reported diffuse emissions of CH<sub>4</sub> are based on a measurement derived emission factor of 5 kg CH<sub>4</sub> per operating hour. See chapter 9 for details concerning the EFs used for indirect CO<sub>2</sub> emissions from CH<sub>4</sub> and NMVOC.

#### 4.3.7.5 Uncertainties and time-series consistency

Uncertainty estimates are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### 4.3.7.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### **4.3.7.7 Category-specific recalculations**

Reallocation: Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

#### **4.3.7.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.3.8 Other, plastic, 2B8g**

#### **4.3.8.1 Category description**

The emissions included in this category are from a plant that now produces polyethylene and a plant that produces formalin and binders. They are both part of the EU ETS. The emissions reported in this category includes all emissions from the plant producing polyethylene and the process emissions from the plant producing formalin and binders. except for minor emissions from the combustion of diesel and heating oil, these are reported under 1A2C.

#### **4.3.8.2 Methodological issues**

##### CO<sub>2</sub>, CH<sub>4</sub> and NMVOC

The plant producing polyethylene reports emission figures of CO<sub>2</sub>, CH<sub>4</sub> and NMVOC to the Norwegian Environment Agency. The reported emissions from flaring and combustion of fuels are based on the amounts of fuels multiplied by emission factors. Statistics Norway allocates these emissions in IPPU and ensures that emissions from this fuel use are not also reported under Energy. CH<sub>4</sub> and NMVOC emissions reported are based on measurements. Indirect emissions of CO<sub>2</sub> calculated by Statistics Norway are based on the emissions of CH<sub>4</sub> and NMVOC.

The plant that produces formalin and binders reports CO<sub>2</sub> emissions to the Norwegian Environment Agency. The process emissions reported under IPPU are since 2013 based on a mass balance taking into account the produced amounts of formalin and the amounts of methanol used in the process. The IEFs for the process emissions calculated as tonnes CO<sub>2</sub> per tonne formalin produced is in the range of 0.15-0.18 for the years 2013-2019. The average of 0.168 has been used together with the production levels of formalin to estimate the process emissions for the years 1990-2012.

#### 4.3.8.3 Activity data

The annual emissions from the plant producing polyethylene are from flaring and combustion of fuels and are based on the reported combusted amounts. The majority of this is natural gas, but there is also some flaring gas and hazardous waste.

**Table 4.22 Sum of fuels (kt) used in production of polyethylene.**

| 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|------|------|------|------|------|
| 5    | 5    | 4    | 5    | 5    | 5    | 8    |

Source: Norwegian Environment Agency

The production volumes of polyethylene and polypropylene are aggregated and reported in CRF table2(I).A-Hs1. The production volume of polyethylene in 2021 was about 124 ktonnes and the production of formalin (100%) in 2021 was about 38 ktonnes.

#### 4.3.8.4 Emission factors

CO<sub>2</sub>

The plants report the emission factors used as part of their reporting under the EU ETS.

#### 4.3.8.5 Uncertainties and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex II. A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### 4.3.8.6 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plant is covered by the EU ETS and the emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### 4.3.8.7 Category-specific recalculations

**Reallocation:** Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> and NMVOC are now reported separately in CRF Table 6.

Revised activity data for the two plants, resulting in a decrease in CO<sub>2</sub> emissions in the period 1990 to 2018, with largest impact in 2005 and 2006 with a reduction of 4kt and 8kt respectively.

#### 4.3.8.8 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

#### 4.3.9 Other, production of fertilizers, 2B10

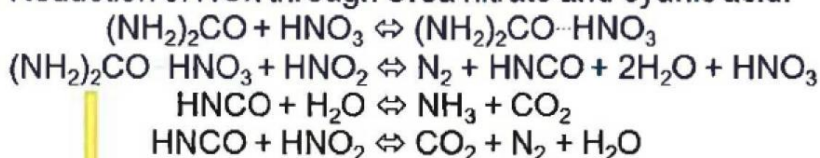
##### 4.3.9.1 Category description

A plant producing fertilizers has since 2011 reported N<sub>2</sub>O emissions from its production to the agency. Urea nitrate is added to the process to reduce the formation of NO<sub>x</sub> emissions and this process forms N<sub>2</sub>O emissions.

##### 4.3.9.2 Methodological issues

According to the plant, the formation of NO<sub>x</sub> is reduced through the use of urea nitrate and cyanic acid. The process forms N<sub>2</sub>O, see formulas below.

**Reduction of NO<sub>x</sub> through Urea nitrate and cyanic acid:**



**N<sub>2</sub>O formation:**



The emissions of N<sub>2</sub>O are based on measurements of gas volumes and samples are taken for analysis by gas chromatograph. The plant has reported N<sub>2</sub>O emissions since 2011 and the Norwegian Environment Agency has estimated the emissions for the years 1990-2010 based on production levels and assumptions about the IEF. There are many factors that influence the emissions, and these have varied over time. Such factors are production levels, composition of phosphates, use of urea etc. The plant's reporting of emissions for the years 2011-2013 results in an average IEF of 0.27 kg N<sub>2</sub>O per tonne produced fertilizer.

This IEF was used to estimate the emissions for the years 2007-2010 as the factors influencing the emissions were similar to 2011-2013. In the years 2002-2006, the plant used more of one type of phosphate than in the period 2007-2013 and the IEF is therefore assumed to be 25% lower. The use of the phosphate type was even larger in the years 1990-2001 and the IEF is therefore assumed to be 50% lower than for the years 2007-2013.

#### **4.3.9.3 Activity data**

See description in chapter 4.3.9.2. Although there are several factors that influence the emissions, the production of fertilizers is included as activity data in CTF table 2(I).A-Hs1.

#### **4.3.9.4 Emission factors**

See description in chapter 4.3.9.2.

#### **4.3.9.5 Uncertainties and time-series consistency**

The estimates for the years 1990-2010 are uncertain since there are many factors that could influence the emissions. Chapter 4.3.9.2 describes how the emissions for 1990-2010 were estimated and explains the differences in IEF over time. Uncertainty estimates for greenhouse gases are given in Annex II.

#### **4.3.9.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The emissions in this category are not covered by the EU ETS, but the emissions have been reported since 2011 and are considered and tracked by the agency's inventory team.

#### **4.3.9.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.3.9.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 4.4 Metal industry – 2C

The Metal industry in Norway includes plants producing iron and steel, ferroalloys, aluminium, magnesium, zink, anodes and nickel, see [Table 4.23](#). Nearly all emissions figures from the production of metals included in the inventory are figures reported annually from the plants to the agency.

**Table 4.23 Metal industry. Components included in the inventory, tier of method and key category.**

| Source category                 | CO <sub>2</sub> | CH <sub>4</sub> | PFCs | SF <sub>6</sub> | Tier     | Key category |
|---------------------------------|-----------------|-----------------|------|-----------------|----------|--------------|
| 2C1a. Iron and steel production | R               | NA              | NA   | NA              | Tier 3   | No           |
| 2C2. Ferroalloys production *   | R               | R               | NA   | NA              | Tier 2/3 | Yes          |
| 2C3. Aluminium production       | R               | NA              | R    | R               | Tier 2/3 | Yes          |
| 2C4. Magnesium production       | E               | NA              | NA   | R               | Tier 2   | Yes          |
| 2C6. Zink production            | R + E           | NA              | NA   | NA              | Tier 2   | No           |
| 2C7. Anode production           | R               | NA              | NA   | NA              | Tier 2   | No           |
| 2C7. Nickel production          | R               | NA              | NA   | NA              | Tier 2   | No           |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occuring. IE = Included Elsewhere.*

*\* Small N<sub>2</sub>O emissions from 2C2 are reported under 2C7 Ferroalloys N<sub>2</sub>O in the CRF*

Table 4.24 shows the trends for the sector Metal Production (2C) as a whole and for the various source categories. The GHG emissions from this sector category were about 5.3 million tonnes in 2021, this is 59% of the total emission from the IPPU-sector. The largest contributors to the GHG emissions from Metal industry in 2021 are Ferroalloy production and Aluminium production. The emissions from Metal Production have decreased by 45.6% from 1990. The reduction since 1990 is due to decreased PFC and SF<sub>6</sub> emissions that again were due to improvement in technology in aluminium production, the close down of a magnesium plant in 2006 and generally lower production volumes. The emissions increased by 6.7% from 2020 to 2021. There was a large increase in emissions from 2009 to 2010, this is mainly due to a low production level for ferroalloys in 2009. The production level in 2009 is also lower than 2008 and reflects the lower economic activity due to the economic recession.

| <b>Table 4.24 Emission trends for 2C Metal industry (t CO<sub>2</sub> equivalents).</b> |           |                       |           |           |                    |                               |                            |
|-----------------------------------------------------------------------------------------|-----------|-----------------------|-----------|-----------|--------------------|-------------------------------|----------------------------|
| Source category                                                                         | 1990      | 1990,<br>% of<br>IPPU | 2020      | 2021      | 2021, %<br>of IPPU | Trend<br>1990-<br>2021<br>(%) | Trend<br>2020-<br>2021 (%) |
| 2C1a. Iron and steel production                                                         | 12 350    | 0.1                   | 32 146    | 32 594    | 0.4                | 163.9                         | 1.4                        |
| 2C2. Ferroalloys production                                                             | 2 554 955 | 17.4                  | 2 692 860 | 2 786 813 | 30.9               | 9.1                           | 3.5                        |
| 2C3. Aluminium production                                                               | 4 918 843 | 33.5                  | 2 162 300 | 2 390 283 | 26.5               | -51.4                         | 10.5                       |
| 2C4. Magnesium production                                                               | 2 235 598 | 15.2                  | 0         | 0         | 0.0                | -100.0                        | NA                         |
| 2C6. Zinc production                                                                    | 2 956     | 0.0                   | 5 188     | 4 889     | 0.1                | 65.4                          | -5.8                       |
| 2C7 Ferroalloys N <sub>2</sub> O                                                        | 4 466     | 0.0                   | 4 098     | 3 710     | 0.0                | -16.9                         | -9.5                       |
| 2C7 Anode production                                                                    | 43 814    | 0.3                   | 74 866    | 83 938    | 0.9                | 91.6                          | 12.1                       |
| 2C7 Nickel production                                                                   | 7 600     | 0.1                   | 14 320    | 15 600    | 0.2                | 105.3                         | 8.9                        |
| 2C. Total                                                                               | 9 780 583 | 66,5                  | 4 985 777 | 5 317 827 | 59,0               | -45,6                         | 6,7                        |

Source: Statistics Norway and the Norwegian Environment Agency

#### 4.4.1 Steel, 2C1a

##### 4.4.1.1 Category description

Norway includes one plant producing steel that is covered by the EU ETS and the activity data in the CRF is steel produced.

##### 4.4.1.2 Methodological issues

The total emissions from steel production cover emissions from industrial processes and from combustion, but only the process emissions are reported in this sub-category.

Emission figures of CO<sub>2</sub> annually reported to the Norwegian Environment Agency are used in the Norwegian GHG Inventory. This reporting includes both the reporting under the EU ETS and reporting as required under its regular emission permit. The emission figures are based on mass balance calculations.

##### 4.4.1.3 Activity data

The process CO<sub>2</sub> emissions stem from an Electric Arc Furnace (EAF) where scrap iron is melted with other carbon materials. The emissions from the scrap iron are calculated based on the use of each type of scrap iron and the appurtenant content of carbon in each

type of scrap iron. The types of scrap iron are according to the UK steel protocol and the carbon content in the types of scrap used varies from 0.15% up to 4%. The other input materials to the EAF are coal, lime and the metals ferromanganese, ferrosilicon and silicomanganese and electrodes. The outputs are steel, dust and slag. The net emissions from the mass balance are the process emissions.

#### **4.4.1.4 Emission factors**

Since a mass balance is used, it is the carbon contents of the carbon materials that go into the mass balance that are used. For the scrap iron, all ten types of scrap iron have their own carbon content.

#### **4.4.1.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category. The process emissions prior to 2005 have to a large extent been estimated based on the process emissions per tonne steel produced in 1998 and 2005, this explains the increasing variation in the CO<sub>2</sub> IEF for steel after 2005 since the emissions from 2005 and onwards are based on annual reported data from the EU ETS.

#### **4.4.1.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plant is covered by the EU ETS and the emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### **4.4.1.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.4.1.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

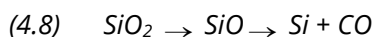
### **4.4.2 Production of Ferroalloys, 2C2 (Key category for CO<sub>2</sub>)**

#### **4.4.2.1 Category description**

There are 12 plants producing ferroalloys in Norway and the plants were included in the EU ETS in 2013. One plant closed in 2001, two plants were closed down during 2003 and two in 2006. The plant that was out of production in 2006 started up again in 2007. Ferrosilicon, silicon metal, ferromanganese and silicon manganese are now produced in Norway.



Ferrochromium was produced until the summer in 2001. Ferro silicon with 65 to 96% Si and silicon metal with 98-99% Si is produced. The raw material for silicon is quartz ( $\text{SiO}_2$ ).  $\text{SiO}_2$  is reduced to Si and CO using reducing agents like coal, coke, and charcoal.



The waste gas CO and some SiO burns to form  $\text{CO}_2$  and  $\text{SiO}_2$  (silica dust).

In ferroalloy production, raw ore, carbon materials and slag forming materials are mixed and heated to high temperatures for reduction and smelting. The carbon materials used are coal, coke, and some bio carbon (charcoal and wood). Electric submerged arc furnaces with graphite electrodes or consumable Soederberg electrodes are used. The heat is produced by the electric arcs and by the resistance in the charge materials. The furnaces used in Norway are open, semi-covered or covered.

The CO is a result of the production process. In open or semi- closed furnaces, the CO reacts with air and forms  $\text{CO}_2$  before it is emitted. This is due to high temperature and access to air in the process. In a closed furnace the CO does not reach to  $\text{CO}_2$  as there are no access to air (oxygen) in the process. The waste gas is then led from furnace and used as an energy source or flared and is reported under the relevant Energy sectors. The technical specification of the furnaces is irrelevant since emissions are calculated using a mass balance or calculated by multiplying the amount of reducing agents in dry weight with country specific EFs.

Several components are emitted from production of ferroalloys. Emission of  $\text{CO}_2$  is a result of the oxidation of the reducing agent used in the production of ferroalloys. In the production of FeSi and silicon metal NMVOC and  $\text{CH}_4$  emissions originates from the use of coal and coke in the production processes. From the production of ferro manganese (FeMn), silicon manganese (SiMn) and ferrochromium (FeCr) there is only  $\text{CO}_2$  emissions. Measurements performed at Norwegian plants producing ferroalloys indicate that in addition to emissions of  $\text{CO}_2$  and  $\text{CH}_4$  also  $\text{N}_2\text{O}$  is emitted. Due to the CRF, the  $\text{N}_2\text{O}$  emissions are reported in 2C7i (ferroalloys  $\text{N}_2\text{O}$ ).

The large increase in emissions from 2009 to 2010 is due to a low production level for ferroalloys in 2009. The production level in 2009 is also lower than 2008 and reflects the lower economic activity due to the economic recession.

CO<sub>2</sub> emissions from production of ferroalloys is defined as a key category according to the approach 2 analysis.

#### **4.4.2.2 Methodological issues**

##### CO<sub>2</sub>

The methods used in the calculation of CO<sub>2</sub> emissions from production of ferroalloy is in accordance with the method recommended by the IPCC (2006). Emissions are reported by each plant in an annual report to the agency.

The plants have used one of the two methods below for calculating CO<sub>2</sub>-emissions:

- Mass balance: the emission of CO<sub>2</sub> is calculated by adding the total input of C in raw materials before subtracting the total amount of C in products, wastes and sold gases (Tier 3).
- Calculate emission by multiplying the amount of reducing agents in dry weight with country specific emission factors for coal, coke, petrol coke, electrodes, anthracite, limestone, and dolomite (Tier 2).

Each plant has for consistency just used one method for the entire time series.

Indirect emissions of CO<sub>2</sub> are calculated based on the emission of CH<sub>4</sub> and are reported in CRF table 6.

##### CH<sub>4</sub> and N<sub>2</sub>O

The emissions of CH<sub>4</sub> and N<sub>2</sub>O are calculated by multiplying the amount of ferroalloy produced with an emission factor. Emissions are reported by each plant in an annual report to the agency.

Plants producing ferro manganese, silicon manganese and ferrochromium do not emit emissions of CH<sub>4</sub> and N<sub>2</sub>O.

##### NM VOC

The emissions are estimated by Statistics Norway from the consumption of reducing agents and an emission factor.

#### **4.4.2.3 Activity data**

##### CO<sub>2</sub>

Calculation of emissions is based on the consumption of gross reducing agents and raw materials (carbonate ore, limestone, and dolomite). Note that the use of limestone and dolomite and the corresponding emissions are included here under 2C2.

Table 4.25 shows the amount of reducing agents used as activity data in the CRF for some selected years. The reducing agents include the use of bio carbon and the use increased from about 2001.

| <b>Table 4.25 Ktonnes of reducing agents in the ferroalloys production for some selected years.</b> |       |         |       |         |         |
|-----------------------------------------------------------------------------------------------------|-------|---------|-------|---------|---------|
| Activity data                                                                                       | 1990  | 2000    | 2010  | 2020    | 2021    |
| Coal (dry weight)                                                                                   | 395.3 | 544.9   | 360.3 | 581.3   | 613.6   |
| Coke (dry weight)                                                                                   | 379.0 | 450.1   | 328.0 | 306.4   | 317.5   |
| Electrodes                                                                                          | 34.7  | 48.1    | 48.8  | 47.7    | 49.6    |
| Petrol coke                                                                                         | 8.4   | 12.9    | 7.8   | 2.3     | 0.9     |
| Pulverised coke                                                                                     | 0.0   | 0.0     | 9.7   | 1.3     | 3.9     |
| Bio carbon                                                                                          | 16.6  | 17.5    | 104.0 | 182.2   | 196.7   |
| Total                                                                                               | 834.0 | 1 073.6 | 858.6 | 1 121.0 | 1 182.2 |
| Bio as % of total                                                                                   | 2%    | 2%      | 12%   | 16%     | 17%     |

Source: Norwegian Environment Agency

#### CH<sub>4</sub> and N<sub>2</sub>O

The gross production of different ferroalloys is used in the calculation.

#### NMVOC

The gross amount of reducing agents that are used for the calculation of NMVOC emissions are annually reported to Statistics Norway from each plant.

#### **4.4.2.4 Emission factors**

##### CO<sub>2</sub>

The carbon content of each raw materials used in the Tier 3 calculation is from carbon certificates from the suppliers. The carbon in each product, CO gas sold et cetera is calculated from the mass of product and carbon content. In the Tier 2 calculation the emission factors are as listed in Table 4.26.

**Table 4.26 Emission factors from production of ferroalloys. Tonnes CO<sub>2</sub>/tonne reducing agent or electrode.**

|                   | Coal | Coke | Electrodes | Petrol coke | Carbonate ore | Dolomite Limestone |
|-------------------|------|------|------------|-------------|---------------|--------------------|
| Ferro silicon     | 3.08 | 3.36 | 3.36       | --          | --            | --                 |
| Silicon metal     | 3.12 | 3.36 | 3.54       | --          | --            | --                 |
| Ferro chromium    | --   | 3.22 | 3.51       | --          | --            | --                 |
| Silicon manganese | --   | 3.24 | 3.51       | 3.59        | 0.16- 0.35    | 0.43-0.47          |
| Ferro manganese   | --   | 3.24 | 3.51       | 3.59        | 0.16- 0.35    | 0.43-0.47          |

Source: SINTEF (1998a); SINTEF (1998b); SINTEF (1998c)

### CH<sub>4</sub> and N<sub>2</sub>O

Measurements performed at Norwegian plants producing ferro alloys indicate emissions of N<sub>2</sub>O in addition to CH<sub>4</sub>. The emissions of CH<sub>4</sub> and N<sub>2</sub>O are influenced by the following parameters:

- The silicon level of the alloy (65, 75, 90 or 98% Si) and the silicon yield
- The method used for charging the furnace (batch or continuously)
- The amount of air used to burn the gases at the top controlling the temperature in off gases.

Measurement campaigns at silicon alloy furnaces have been performed since 1995, and these measurements are the base for the values in the BREF document for silicon alloys. The results of the measurements, that the emissions factors in the Norwegian CH<sub>4</sub> and N<sub>2</sub>O are based upon, are presented in SINTEF (2004). A summary of the report is given in the publication "Reduction of emissions from ferroalloy furnaces" (Grådahl et al. 2007). The focus for the studies has been NO<sub>x</sub> emissions. However, the emissions of CH<sub>4</sub> and N<sub>2</sub>O have also been measured.

Full scale measurements have been performed at different industrial FeSi/Si furnaces. The average CH<sub>4</sub> and N<sub>2</sub>O concentrations in the ferroalloy process are with some exceptions a few ppm. For N<sub>2</sub>O and CH<sub>4</sub> the exception is during spontaneous avalanches in the charge (i.e. collapse of large quantities of colder materials falling into the crater or create cavities) occur from time to time, see figure 7 in Grådahl et al. (2007). In the avalanches the N<sub>2</sub>O emissions go from around zero to more than 35 ppm. The avalanches are always short in duration. There are also increased N<sub>2</sub>O emissions during blowing phenomenon.

The EF used in the inventory represents the longer-term average N<sub>2</sub>O and CH<sub>4</sub> concentration measurements outside the peaks in concentrations. The peaks in

concentration occur due to avalanches (sudden fall of large amount of colder charge into the furnace) that occur from time to time is not fully reflected in the EFs. The EFs used we regard as conservative particular for the early 1990s when the avalanches were more frequent than the latest years.

All companies apply sector specific emission factors in the emission calculation, see [Table 4.27](#). The factors are developed by the Norwegian Ferroalloy Producers Research Organisation (FFF) and standardized in meeting with The Federation of Norwegian Process Industries (PIL) (today named Federation of Norwegian Industries) in February 2007.

#### NMVOC

Statistics Norway uses an emission factor of 1.7 kg NMVOC/tonne coal or coke in the calculations (Limberakis et al. 1987).

**Table 4.27 Emission factors for CH<sub>4</sub> and N<sub>2</sub>O from production of ferroalloys.**

|                                          | Si-met         |                                |                                           | FeSi-75%       |                                |                                           | FeSi-65%       |                                |                                           |
|------------------------------------------|----------------|--------------------------------|-------------------------------------------|----------------|--------------------------------|-------------------------------------------|----------------|--------------------------------|-------------------------------------------|
| Alloy, charging routines and temperature | Batch-charging | Sprinkle-charging <sup>1</sup> | Sprinkle-charging and >750°C <sup>2</sup> | Batch-charging | Sprinkle-charging <sup>1</sup> | Sprinkle-charging and >750°C <sup>2</sup> | Batch-charging | Sprinkle-charging <sup>1</sup> | Sprinkle-charging and >750°C <sup>2</sup> |
| kg CH <sub>4</sub> per tonne metal       | 0.1187 (M)     | 0.0881 (M)                     | 0.1000 (E)                                | 0.0890 (E)     | 0.0661 (E)                     | 0.0750 (E)                                | 0.0772 (E)     | 0.0573 (E)                     | 0.0650 (E)                                |
| kg N <sub>2</sub> O per tonne metal      | 0.0433 (E)     | 0.0214 (E)                     | 0.0252 (E)                                | 0.0297 (E)     | 0.0136 (E)                     | 0.0161 (E)                                | 0.0117 (E)     | 0.0078 (E)                     | 0.0097 (E)                                |

<sup>1</sup> Sprinkle-charging is charging intermittently every minute.

<sup>2</sup> Temperature in off-gas channel measured where the thermocouple cannot 'see' the combustion in the furnace hood.

M=measurements and E= estimates based on measurements

#### 4.4.2.5 Uncertainties and time-series consistency

The uncertainty in activity data and emission factors have been calculated to ±5% and ±7% respectively, see Annex II.

The IEF (tonne CO<sub>2</sub>/tonne reducing agent) for the ferroalloys production has a downward trend from around the year 2001. This is due to the increased use of bio carbons. Fluctuations in the IEF can also be due to variations in use of the various reducing agents, amounts of sold CO and production of ferro alloy products.

#### **4.4.2.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants have reported under the voluntary agreement and the emissions are now covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

Statistics Norway makes in addition occasional quality controls (QC) of the emission data based on the consumption of reducing agents they collect in an annual survey and average emission factors.

#### **4.4.2.7 Category-specific recalculations**

*Reallocation:* Indirect emissions of CO<sub>2</sub> from emissions of CH<sub>4</sub> are now reported separately in CRF Table 6.

#### **4.4.2.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.4.3 Aluminium production, 2C3 (Key Category for CO<sub>2</sub> and PFC)**

#### **4.4.3.1 Category description**

One open mill in Norway has handled secondary aluminium production, but it closed in 2001. Minor emissions of SF<sub>6</sub> in the period 1992-2000 are therefore included in the inventory.

There are seven plants in Norway producing primary aluminium and they were included into the EU ETS in 2013. Both prebaked anode and the Soederberg production methods are used. In the Soederberg technology, the anodes are baked in the electrolysis oven, while in the prebaked technology the anodes are baked in a separate plant. In general, the emissions are larger from the Soederberg technology than from the prebaked technology. Production of aluminium leads to emission of CO<sub>2</sub> and perfluorocarbons (PFCs). The emission of CO<sub>2</sub> is due to the electrolysis process during the production of aluminium.

There has been a substantial reduction in the total PFC emissions from the seven Norwegian aluminium plants since 1990. This is a result of the sustained work and the strong focus on reduction of the anode effect frequency in all these pot lines and that there has been a shift from Soederberg to prebaked technology. The focus on reducing anode effect frequency started to produce results from 1992 for both technologies. For prebaked technology the PFC emissions in kg CO<sub>2</sub> equivalents per tonne aluminium were reduced

from 2.69 in 1990 to 2.07 in 1991 and 1.01 in 1992 and respective values for Soederberg were 5.79, 5.47 and 5.20. In 2021 the specific PFC emissions for prebaked and Soederberg were 0.16 and 0.12 kg CO<sub>2</sub> equivalent, see Figure 4-5 and Table 4.28.

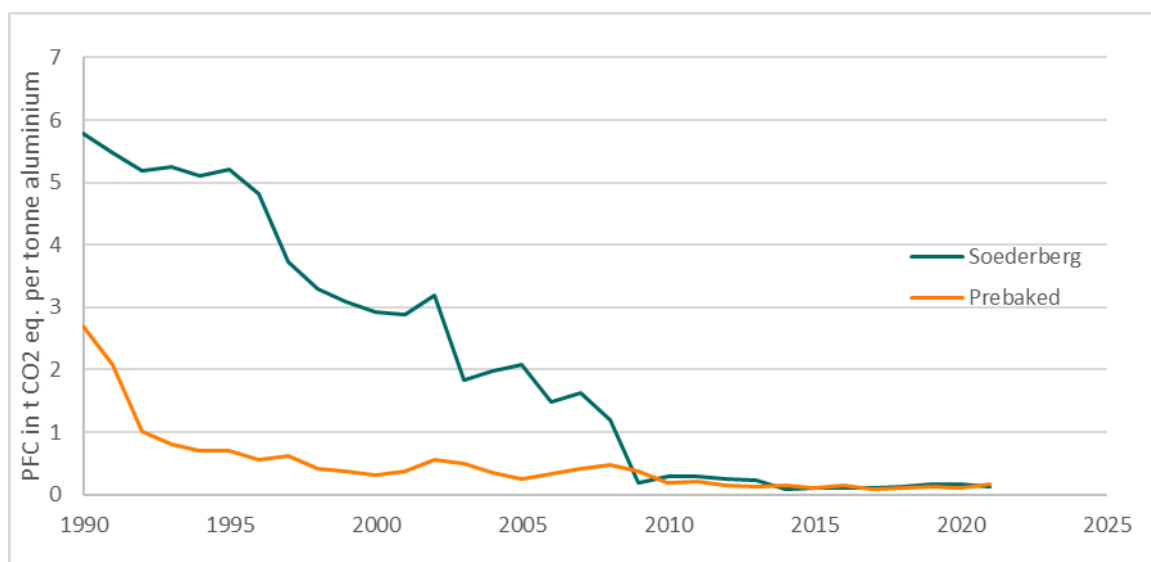


Figure 4-5 PFC in tonne CO<sub>2</sub> equivalent per tonne aluminium. Source: Norwegian Environment Agency

**Table 4.28 Shares of the technologies used in aluminium production and the PFC IEFs. PFC in kg CO<sub>2</sub> equivalents per tonne aluminium.**

| Year | Share of production from Soederberg technology | Share of production from pre-baked technology | PFC IEF Soderberg | PFC IEF pre-baked |
|------|------------------------------------------------|-----------------------------------------------|-------------------|-------------------|
| 1990 | 43%                                            | 57%                                           | 5.79              | 2.69              |
| 1995 | 39%                                            | 61%                                           | 5.22              | 0.70              |
| 2000 | 39%                                            | 61%                                           | 2.92              | 0.32              |
| 2005 | 20%                                            | 80%                                           | 2.08              | 0.25              |
| 2010 | 8%                                             | 92%                                           | 0.28              | 0.19              |
| 2012 | 7%                                             | 93%                                           | 0.26              | 0.15              |
| 2013 | 8%                                             | 92%                                           | 0.24              | 0.13              |
| 2014 | 8%                                             | 92%                                           | 0.09              | 0.14              |
| 2015 | 8%                                             | 92%                                           | 0.11              | 0.11              |
| 2016 | 8%                                             | 92%                                           | 0.10              | 0.14              |
| 2017 | 7%                                             | 93%                                           | 0.10              | 0.09              |
| 2018 | 7%                                             | 93%                                           | 0.13              | 0.10              |
| 2019 | 7%                                             | 93%                                           | 0.17              | 0.12              |
| 2020 | 7%                                             | 93%                                           | 0.16              | 0.11              |
| 2021 | 7%                                             | 93%                                           | 0.12              | 0.16              |

Source: Norwegian Environment Agency

In 1990, 57% of the aluminium production in Norway was produced with prebaked technology and the share of aluminium production from prebaked was increased to 93% in 2021. Two new plants with prebaked technology were established in 2002 and plants using Soederberg technology were closed down in the period 2002-2009. The shares of the two technologies and their PCF IEFs are shown in [Table 4.28](#). The PFCs emissions from production of aluminium have decreased by 93.6% from 1990 to 2021 but increased by 53.5 per cent between 2020 and 2021. The increase in PFC emissions in 2021 is primarily due to increased production at one of the plants that has increased its production capacity. The production from this plant increased from about 94 kt aluminium in 2020 to about 169 kt aluminium in 2021.

The PFC emissions per tonne aluminium produced in Norway was 4.02 kg CO<sub>2</sub> equivalents in 1990 and 0.16 kg CO<sub>2</sub> equivalents in 2021. This is a reduction of 96.1% since 1990.

An increase in production capacity is also included in the modernisation, leading to higher total emissions of CO<sub>2</sub>. PFCs and CO<sub>2</sub> emissions from aluminium production are both identified as key categories according to the approach 2 analysis.

#### **4.4.3.2 Methodological issues**

##### CO<sub>2</sub>

The inventory uses the emission figures reported to the Norwegian Environment Agency calculated by each plant.

For the years including 2012, the aluminium industry calculated the CO<sub>2</sub> emissions separate for each technology based on consumption of reducing agents. This includes carbon electrodes, electrode mass and petroleum coke. The emissions factors are primarily calculated from the carbon content of the reducing agents.

The following methods were used up to 2012:

##### CO<sub>2</sub> from Prebake Cells

$$(4.9) \quad Q = A \cdot C \cdot 3.67$$

Where:

Q is the total yearly emissions of CO<sub>2</sub>

A is the yearly net consumption of anodes

C is % carbon in the anodes



3.67 is the mol-factor CO<sub>2</sub>/C

#### CO<sub>2</sub> from Soederberg Cells

$$(4.10) \quad Q = S \cdot 3.67 \cdot (K \cdot C1 + P \cdot C2)$$

Where:

Q is the total yearly emissions of CO<sub>2</sub>

S is the yearly consumption of Soederberg paste

K is the share of coke in the Soederberg paste

P is the share of pitch in the Soederberg paste

K+P=1

C1 is the fraction of carbon in the coke. Fraction is % Carbon/100

C2 is the fraction of carbon in the pitch. Fraction is % Carbon/100

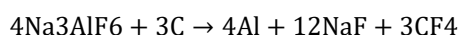
From 2013 and onwards, the CO<sub>2</sub> emissions from Soederberg cells and from Prebake cells are calculated using the mass balance methodology that considers all carbon inputs, stocks, products and other exports from the mixing, forming, baking and recycling of electrodes as well as from electrode consumption in electrolysis. We have no indications that this has resulted in an inconsistent time series.

#### PFCs

Perfluorinated hydrocarbons (PFCs), e.g., tetrafluoromethane (CF<sub>4</sub>) and hexafluoroethane (C<sub>2</sub>F<sub>6</sub>), are produced during anode effects (AE) in the Prebake and Soederberg cells, when the voltage of the cells increases from the normal 4-5V to 25-40V. During normal operating condition, PFCs are not produced. The fluorine in the PFCs produced during anode effects originates from cryolite. Molten cryolite is necessary as a solvent for alumina in the production process.

Emissions of PFCs from a pot line (or from smelters) are dependent on the number of anode effects and their intensity and duration. Anode effect characteristics will be different from plant to plant and also depend on the technology used (Prebake or Soederberg). During electrolysis two per fluorocarbon gases (PFCs), tetrafluoromethane (CF<sub>4</sub>) and hexafluoroethane (C<sub>2</sub>F<sub>6</sub>), may be produced in the following reactions:

Reaction 1



Reaction 2



The national data are based on calculated plant specific figures from each of the Norwegian plants. A Tier 2 method is used in the calculations, which are based on a technology specific relationship between anode effect performance and PFCs emissions. The PFCs emissions are then calculated by the so-called slope method, where a constant slope coefficient (see Table 4.29), is multiplied by the product of anode effect frequency and anode effect duration (in other words, by the number of anode effect minutes per cell day), and this product is finally multiplied by the annual aluminium production figure (tonnes of Al/year). The formula for calculating the PFCs is:

$$\text{kg CF}_4 \text{ per year} = S_{\text{CF}_4} \cdot \text{AEM} \cdot \text{MP and}$$

$$\text{kg C}_2\text{F}_6 \text{ per year} = \text{kg CF}_4 \text{ per year} \cdot F_{\text{C}_2\text{F}_6/\text{CF}_4}$$

Where:

$S_{\text{CF}_4}$  = "Slope coefficient" for  $\text{CF}_4$ , ( $\text{kg}_{\text{PFC}}/\text{t}_{\text{Al}}$ )/anode effect minutes/cell day

AEM = anode effect minutes per cell day

MP = aluminium production, tonnes Al per year

$F_{\text{C}_2\text{F}_6/\text{CF}_4}$  = weight fraction of  $\text{C}_2\text{F}_6/\text{CF}_4$

**Table 4.29 Technology specific slope coefficients and weight fractions for the calculation of PFCs emissions from aluminium production.**

| Technology <sup>a</sup> | "Slope coefficient" <sup>b, c</sup><br>( $\text{kg}_{\text{PFC}}/\text{t}_{\text{Al}}$ )/ (anode effect/cellday) |                  | Weight fraction $\text{C}_2\text{F}_6/\text{CF}_4$ |                  |
|-------------------------|------------------------------------------------------------------------------------------------------------------|------------------|----------------------------------------------------|------------------|
|                         | $S_{\text{CF}_4}$                                                                                                | Uncertainty (±%) | $F_{\text{C}_2\text{F}_6/\text{CF}_4}$             | Uncertainty (±%) |
| CWPB                    | 0.143                                                                                                            | 6                | 0.121                                              | 11               |
| SWPB                    | 0.272                                                                                                            | 15               | 0.252                                              | 23               |
| VSS                     | 0.092                                                                                                            | 17               | 0.053                                              | 15               |
| HSS                     | 0.099                                                                                                            | 44               | 0.085                                              | 48               |

*a. Centre Worked Prebake (CWPB), Side Worked Prebake (SWPB), Vertical Stud Søderberg (VSS), Horizontal Stud Søderberg (HSS).*

*b. Source: Measurements reported to IAI, US EPA sponsored measurements and multiple site measurements.*

*c. Embedded in each slope coefficient is an assumed emission collection efficiency as follows: CWPB 98%, SWPB 90%, VSS 85%, HSS 90%. These collection efficiencies have been assumed based on measured PFC collection fractions, measured fluoride collection efficiencies and expert opinion.*

*"Slope coefficient": The connection between the anode parameters and emissions of PFC.*

Measurements of PFCs at several aluminium plants have established a connection between anode parameters and emissions of  $\text{CF}_4$  and  $\text{C}_2\text{F}_6$ . The mechanisms for producing emissions of PFC are the same as for producing  $\text{CF}_4$  and  $\text{C}_2\text{F}_6$ . The two PFC gases are therefore considered together when PFC emissions are calculated. The  $\text{C}_2\text{F}_6$  emissions are calculated as a fraction of the  $\text{CF}_4$  emissions.

The Tier 2 coefficients for Centre Worked Prebaked cells (CWPB) are average values from about 70 international measurement campaigns made during the last decade, while there are fewer data (less than 20) for Vertical Stud Soederberg cells (VSS). The main reason for the choice of the Tier 2 method is that the uncertainties in the facility specific slope coefficients is lower than the facility specific based slope coefficients in Tier 3. This means that there is nothing to gain in accuracy of the data by doing measurements with higher uncertainties.

“Slope coefficient” is the number of kg  $\text{CF}_4$  per tonne aluminium produced divided by the number of anode effects per cell day. The parameter cell day is the average number of cells producing on a yearly basis multiplied with the number of days in a year that the cells have been producing.

#### Sulphur hexafluoride ( $\text{SF}_6$ )

$\text{SF}_6$  used as cover gas in the aluminium industry is assumed to be inert, and  $\text{SF}_6$  emissions are therefore assumed to be equal to consumption. At one plant  $\text{SF}_6$  was used as cover gas in the production of a specific quality of aluminium from 1992 to 1996. The aluminium plant no longer produces this quality, which means that  $\text{SF}_6$  emissions have stopped.

#### **4.4.3.3 Activity data**

The consumption of reducing agents and electrodes and the production of aluminium is reported annually to the agency and the latter is reported as activity data in the CRF tables. The mass balance summarising the consumption of reducing agents in 2021 is shown in Table 4.30.

| <b>Table 4.30 Mass balance for aluminium production in 2021.</b> |             |                                |
|------------------------------------------------------------------|-------------|--------------------------------|
| Reducing agent                                                   | Amount (kt) | CO <sub>2</sub> emissions (kt) |
| Petroleum coke                                                   | 241.9       | 859.2                          |
| Prebaked anodes                                                  | 687.8       | 1 175,0                        |
| Pitch                                                            | 65.6        | 224.0                          |
| Coke                                                             | 32.0        | 114.3                          |
| Soda                                                             | 1.1         | 0.5                            |
| Anode remnant                                                    | 146.4       | -202.5                         |
| Waste                                                            | 2.3         | -2.8                           |
| Tar                                                              | 0.1         | -0.3                           |
| Graphite                                                         | 0.04        | 0.2                            |
| Total                                                            | 1 177.2     | 2 167.6                        |

Source: Norwegian Environment Agency

#### PFCs

The basis for the calculations of PFCs is the amount of primary aluminium produced in the pot lines and sent to the cast house. Thus, any remelted metal is not included here.

#### **4.4.3.4 Emission factors**

There are many factors for the carbon contents of the reducing agent that are used for the mass balances reported by the plants. The contents in tonne CO<sub>2</sub>/tonne reducing agent for the most important reducing agents in 2021 are (rounded to two decimals) 3.55-3.61 for petroleum coke, 3.55-3.60 for prebaked anodes and 3.41 for pitch.

The PFC emissions are calculated using the Tier 2 recommended values by IAI (2005) for CF<sub>4</sub> (the slope coefficients of 0.143 kg CF<sub>4</sub>/tonne Al/anode effect minutes per cell day for CWPB and 0.092 for VSS). The amount of C<sub>2</sub>F<sub>6</sub> is calculated from the Tier 2 values for CF<sub>4</sub>, where the weight fraction of C<sub>2</sub>F<sub>6</sub> to CF<sub>4</sub> is set equal to 0.121 for CWPB and 0.053 for VSS. This is consistent with the 2006 IPCC GL. All values are technology specific data, recommended by IAI. Our facility specific measured data that we have used until today are all in agreement with these data, within the uncertainty range of the measurement method employed.

#### **4.4.3.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

#### PFCs

The uncertainties in the so-called Tier 2 slope coefficients from IAI is lower (6% and 17% for CWPB and VSS cells, respectively), compared to the measured facility specific based slope

coefficients, where the uncertainties are around 20%, even when the most modern measuring equipment is used (the continuous extractive-type Fourier Transform Infrared (FTIR) spectroscopic system). Control measurements in two Hydro Aluminium plants (Karmøy and Sunndal) done by Jerry Marks in November 2004, showed that the measured values for CWPB and VSS cells were well within the uncertainty range of the Tier 2 slope coefficients.

Chapter 4.4.3.1 explains the downward trend of the IEF for PCF emissions, but there are also some inter-annual changes that can be explained. The reduced IEF for Soederberg from 2002 to 2003 is due to the fact that one plant using this technology closed down and had no production in 2003. This plant produced 18% of the aluminium produced with this technology in 2002 and had an IEF in 2002 that was the highest among all the plants producing with Soederberg technology in that year. The reduced IEF for Soederberg from 2008 to 2009 is because another plant using this technology closed in 2009. This plant produced 56% of the aluminium produced with this technology in 2008 and the production in 2009 was minor. The plant's IEF in 2008 was the highest among all the plants producing with Soederberg technology in that year. The variations in the IEF for prebaked between 2014 and 2018 are due variations in the anode effect frequency for one plant.

#### CO<sub>2</sub>

The implied emission factor for CO<sub>2</sub> is relatively stable over the time series. The largest inter-annual changes in the IEF are from 2009 to 2010 and from 2010 to 2011 and can be explained by production problems at one plant in 2010. The concerned plant produced about 18% of the total aluminium in 2010 and uses the prebaked technology. Its CO<sub>2</sub> IEF in 2010 was unusually high since the consumption of anodes per tonne aluminium produced were 22% higher in 2010 than in comparable years.

With the inclusion of the aluminium and anode production in the EU ETS system from 2013, a new methodology was introduced for the calculation of CO<sub>2</sub> emissions from anode production in integrated aluminium and anode plants. For one plant, it was no longer possible to split CO<sub>2</sub> process emission between aluminium and anode production and all the emissions from this plant are reported in 2C3.

#### **4.4.3.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants have reported under the voluntary agreement and the emissions are now covered by the EU ETS and their

emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

As a quality control, it is checked that the reports are complete. Each figure is compared with similar reports from previous years and analysed taking technical changes and utilisation of production capacity during the year into account. If errors are found the Norwegian Environment Agency contacts the plant to discuss the reported data and changes are made if necessary.

The Norwegian Environment Agency has annual meetings with the aluminium industry where all plants are represented. This forum is used for discussion of uncertainties and improvement possibilities. The agency's auditing department are regularly auditing the aluminium plants. As part of the audits, their system for monitoring, calculation and reporting of emissions are controlled.

The emission figures reported by the plants are also occasionally controlled by Statistics Norway. Statistics Norway makes their own estimates based on the consumption of reducing agents and production data collected in an annual survey and average emission factors.

#### **4.4.3.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.4.3.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.4.4 Magnesium production, 2C4 (Key category for SF<sub>6</sub>)**

#### **4.4.4.1 Category description**

There was previously one plant in Norway producing magnesium. The plant closed the production of primary magnesium in 2002 and the production of cast magnesium was closed in 2006. From the mid-1970s, both the magnesium chloride brine process and the chlorination process were used for magnesium production. Since 1991, only the chlorination process was in use.

Production of magnesium leads to process related CO<sub>2</sub> and CO emissions. During the calcinations of Dolomite (MgCa(CO<sub>3</sub>)<sub>2</sub>) to magnesium oxide, CO<sub>2</sub> is emitted. During the next step, magnesium oxide is chlorinated to magnesium chloride and coke is added to bind the oxygen as CO and CO<sub>2</sub>. SO<sub>2</sub> is emitted due to the sulphur in the reducing agent used.

In the foundry, producing cast magnesium, SF<sub>6</sub> is used as a cover gas to prevent oxidation of magnesium. The Norwegian producers of cast magnesium has assessed whether SF<sub>6</sub> used as a cover gas reacts with other components in the furnace. The results indicate that it is relatively inert, and it is therefore assumed that all SF<sub>6</sub> used as cover gas is emitted to the air.

The emissions decreased due to improvements in technology and in process management. The primary magnesium production stopped in 2002 and only secondary production is retained, and this production has no CO<sub>2</sub> emissions from processes. During 2006 also the production of remelting Mg stopped and since then there were no emissions from this source.

SF<sub>6</sub> emissions from magnesium foundries is defined as a key category according to the approach 1 analysis.

#### **4.4.4.2 Methodological issues**

##### CO<sub>2</sub>

The Norwegian emission inventory uses production data as activity data. The CO<sub>2</sub> emissions are therefore calculated by using annual production volume and the emission factor recommended by SINTEF (SINTEF 1998c). This is considered to be in line with the tier 2 method in the IPCC 2006 Guidelines (IPCC 2006).

##### SF<sub>6</sub>

The consumption of the cover gas SF<sub>6</sub> is used as the emission estimates in accordance with the tier 2 method in the IPCC 2006 Guidelines (IPCC 2006). The plant reported the emissions each year to the agency.

#### **4.4.4.3 Activity data**

In the GHG emission inventory we have used production volumes as activity data in the calculation of CO<sub>2</sub>. The plant reported the consumption of SF<sub>6</sub> to the agency.

#### **4.4.4.4 Emission factor**

An emission factor of 4.07 tonnes CO<sub>2</sub>/tonnes produced magnesium is used to calculate the annual emissions of CO<sub>2</sub> (SINTEF 1998c).

#### **4.4.4.5 Uncertainties and time-series consistency**

The uncertainty estimates are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.4.4.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII.

#### **4.4.4.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.4.4.8 Category-specific planned improvements**

Since the plant is closed there is no further planned activity to review historical data.

### **4.4.5 Zinc production, 2C6**

#### **4.4.5.1 Category description**

One plant in Norway produces zinc and the plant's main products are zinc, zinc-alloys and aluminiumfluoride. The plant has reported process emission of CO<sub>2</sub> from the use of ore materials for the year 2012 and onwards.

#### **4.4.5.2 Methodological issues**

CO<sub>2</sub>

The tier 1 method and a default EF from the 2006 IPCC GL is not applicable since the plant uses an electrolytic process and the 2006 IPCC GL states that this does not result in non-energy CO<sub>2</sub> emissions. However, the plant reports some process emissions of CO<sub>2</sub> from the use of ore materials using a mass balance approach for both roasting and sintering. This is 2 method that is more accurate than the tier 1 method because it takes into account the materials and the variety of furnace types used rather than assuming industry-wide practices.

Emission figures have been reported by the plant to the Norwegian Environment Agency for the year 2012 and onwards and the agency has estimated the emissions for the years 1990-2011 by correlating the annual production levels of zinc with the ratio between process and combustion emissions in 2012. For the years 1990-1993 with no production data available, the emissions have been set equal to the emissions in 1994.

#### **4.4.5.3 Activity data**

The plant has reported the amounts of ore materials used for the year 2012 and onwards and it ranges from about 144 000 to 349 000 tonnes. The production of zinc is reported as the AD in CTF table2(I).A-Hs2.



#### **4.4.5.4 Emission factors**

The plant has reported emission factors for the ore materials used for the year 2012 and onwards. The emission factors (t C/t ore material) are in the range of 0.01-0.003.

#### **4.4.5.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.4.5.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plant reports annually through its permit and the agency's inventory team tracks emissions and AD for the plant.

#### **4.4.5.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.4.5.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.4.6 Anode production, 2C7i**

#### **4.4.6.1 Category description**

Four plants in Norway produce anodes and they were included into the EU ETS in 2013. Three plants produce prebaked anodes, and one plant produces coal electrodes. These are alternatives to the use of coal and coke as reducing agents in the production process for aluminium and ferroalloys. The anodes and coal electrodes are produced from coal and coke. The production of anodes and coal electrodes leads to emissions of CO<sub>2</sub>.

#### **4.4.6.2 Methodological issues**

The emissions of CO<sub>2</sub> from the production of anodes are calculated by each plant and the method is based on the Aluminium Sector Greenhouse Gas Protocol by the International Aluminium Institute (IAI 2005).

The emissions are calculated from the consumption of anthracite and petrol coke. In addition, pitch is included in production. The calculations of CO<sub>2</sub> from processes are uptime in hours multiplied with an emission factor for each feedstock. When calcinations of anthracite the EF are 167 kg CO<sub>2</sub> per uptime hour and for petrol coke the EF is 238 kg CO<sub>2</sub>. In addition, there are emissions from energy use that is reported in the Energy sector.

From 2012, there was a methodological challenge for integrated anode and aluminium production plants since reported EU ETS data do not provide information to split emissions on the two processes. Equation 4.21 from the 2006 IPCC Guidelines is not used for calculating these emissions in the EU ETS system, where emissions are calculated based on a carbon mass balance approach without information on ash and sulphur content. Therefore, emissions from two integrated plants that previously were reported under 2C7ai were included under 2C3.

#### **4.4.6.3 Activity data**

See methodological issues.

#### **4.4.6.4 Emission factors**

See methodological issues.

#### **4.4.6.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.4.6.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants have reported under the voluntary agreement and the emissions are now covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### **4.4.6.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.4.6.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.4.7 Nickel production, 2C7ii**

#### **4.4.7.1 Category description**

One plant in Norway produces nickel. During the production of nickel, CO<sub>2</sub> is emitted from the use of soda ash.

#### **4.4.7.2 Methodological issues**

CO<sub>2</sub> emission figures are annually reported from the plant to the agency.

#### **4.4.7.3 Activity data**

The activity data is the annual amounts of soda ash used in the production process, see Table 4.9.

#### **4.4.7.4 Emission factors**

An emission factor of 0.41492 tonnes CO<sub>2</sub>/tonne soda ash is used for the calculations.

#### **4.4.7.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.4.7.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plant reports as required by its regular permit and has also reported under the voluntary agreement. The agency's inventory team tracks emissions and AD for the plant.

#### **4.4.7.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.4.7.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 4.5 Non-energy products from fuels and solvent use – 2D

Norway reports the source categories lubricants use, paraffin wax, solvent use, road paving with asphalt and asphalt roofing under the category 2D, see Table 4.31.

**Table 4.31 Non-energy products from fuels and solvent use. Components included in the inventory, tier of method and key category.**

| Source category                | CO <sub>2</sub> | Tier   | Key category              |
|--------------------------------|-----------------|--------|---------------------------|
| 2D1. Lubricants use            | E               | Tier 2 | Yes                       |
| 2D2. Paraffin wax use          | E               | Tier 1 | No                        |
| 2D3a. Solvent use              | E               | Tier 2 | Yes, at the level of 2D3* |
| 2D3b. Road paving with asphalt | E               | Tier 1 |                           |
| 2D3d. Other (use of urea)      | E               | Tier 1 |                           |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occurring. IE = Included Elsewhere.*

*\* The key category analysis was done at the level of 2D3. Since the emissions from 2D3a and 2D3b are reported in CRF table 6, the remaining source category reported under 2D3 is 2D3d.*

Table 4.32 shows the emission trends for 2D as a whole and for the various source categories. The GHG emissions from this sector category were about 0.1 million tonnes CO<sub>2</sub> equivalents in 2021, this is 1.2% of the total emission from the IPPU-sector. The emissions from the 2D sector decreased by 39.8% from 1990 and the emissions decreased by 0.3% from 2020 to 2021.

**Table 4.32 Emission trends for 2D Non-energy products from fuels and solvent use (t CO<sub>2</sub> equivalents).**

| Source category           | 1990    | 1990, % of IPPU | 2020    | 2021    | 2021, % of IPPU | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
|---------------------------|---------|-----------------|---------|---------|-----------------|---------------------|---------------------|
| 2D1. Lubricants use       | 167 070 | 1.1             | 45 254  | 40 984  | 0.5             | -75.5               | -9.4                |
| 2D2. Paraffin wax use     | 6 234   | 0.0             | 37 614  | 37 899  | 0.4             | 507.9               | 0.8                 |
| 2D3d. Other (use of urea) | 0       | 0.0             | 21 847  | 25 515  | 0.3             | NA                  | 16.8                |
| 2D. Total                 | 173 304 | 1.2             | 104 716 | 104 399 | 1.2             | -39.8               | -0.3                |

*Source: Statistics Norway and the Norwegian Environment Agency*

### 4.5.1 Lubricant use, 2D1 (key category)

#### 4.5.1.1 Category description

Lubricants are mostly used in transportation and industrial applications and are partly consumed during their use. It is difficult to determine which fraction of the consumed

lubricant is actually combusted, and which fraction is firstly resulting in NMVOC and CO emissions and then oxidised to CO<sub>2</sub>. Hence, the total amount of lubricants lost during their use is assumed to be fully oxidized and these emissions are directly reported as CO<sub>2</sub> emissions.

Emissions from waste oil handling are reported in the Energy Sector (energy recovery) and in the Waste sector (incineration).

CO<sub>2</sub> emissions from lubricants use is defined as a key category according to the approach 1 analysis.

#### 4.5.1.2 Methodological issues

The CO<sub>2</sub> emissions from lubricant use are estimated by multiplying sold amounts of lubricants (m<sup>3</sup>) by density, country specific oxidation factors, default NCV value (TJ/tonne), default C content (tonne/TJ) and the mass ratio of CO<sub>2</sub>/C:

$$(4.11) \quad E_p = A_p * d * NCV * ODU_p * CC * 44/12$$

where:

$E_p$  = CO<sub>2</sub> emission from product group  $p$

$A_p$  = Sold amount of lubricant from product group  $p$  (activity data)

$d$  = Density

$NCV$  = Net calorific value for lubricants

$ODU_p$  = Fraction being oxidized during use from product group  $p$

$CC$  = Carbon content

The method is applied to subgroups of lubricants, as does the tier 2 method in the 2006 guidelines. However, even though the lubricant product groups in the Norwegian inventory are more detailed than in the tier 2 method, no distinction is made between lubricant oil and lubricant wax in the activity data. Thus, tier 1 factors are applied for  $NCV$  and  $CC$ .

It is assumed that all lubricant consumption and oxidation occurs within the sales year.

#### 4.5.1.3 Activity data

The sold amount of lubricant by product group is given in Statistics Norway's statistics on sales of petroleum products, see [Table 4.33](#). This statistic is based on reporting from the oil companies and divides the lubricant into five product groups (numbered 204 – 208, see [Table 4.33](#) and [Table 4.34](#)).

| <b>Table 4.33 Sold amounts of lubricants, except to foreign navigation (1.000 m3), 1990 – 2021.</b> |        |        |        |        |        |        |        |       |
|-----------------------------------------------------------------------------------------------------|--------|--------|--------|--------|--------|--------|--------|-------|
| Year                                                                                                | 201    | 202    | 203    | 204    | 205    | 206    | 207    | 208   |
| 1990                                                                                                | 99 637 | 0      | 0      | 0      | 0      | 0      | 0      | 0     |
| 1995                                                                                                | 40 583 | 0      | 0      | 23 270 | 0      | 22 726 | 0      | 0     |
| 2000                                                                                                | 0      | 29 369 | 12 734 | 9 160  | 13 724 | 18 594 | 0      | 0     |
| 2005                                                                                                | 0      | 0      | 0      | 13 215 | 10 751 | 5 919  | 33 671 | 4 233 |
| 2010                                                                                                | 0      | 0      | 0      | 10 412 | 12 189 | 4 147  | 35 434 | 5 514 |
| 2012                                                                                                | 0      | 0      | 0      | 9 405  | 11 665 | 4 188  | 31 168 | 5 813 |
| 2013                                                                                                | 0      | 0      | 0      | 10 161 | 12 515 | 5 195  | 37 047 | 5 944 |
| 2014                                                                                                | 0      | 0      | 0      | 5 655  | 13 627 | 4 898  | 28 504 | 5 973 |
| 2015                                                                                                | 0      | 0      | 0      | 4 419  | 11 612 | 2 317  | 25 416 | 5 188 |
| 2016                                                                                                | 0      | 0      | 0      | 5 230  | 13 352 | 3 300  | 29 586 | 5 922 |
| 2017                                                                                                | 0      | 0      | 0      | 5 254  | 12 640 | 3 251  | 28 937 | 5 961 |
| 2018                                                                                                | 0      | 0      | 0      | 5 518  | 12 898 | 5 291  | 29 802 | 6 210 |
| 2019                                                                                                | 0      | 0      | 0      | 5 548  | 13 320 | 3 563  | 29 249 | 5 728 |
| 2020                                                                                                | 0      | 0      | 0      | 5 772  | 12 989 | 4 448  | 29 041 | 5 191 |
| 2021                                                                                                | 0      | 0      | 0      | 5 461  | 12 818 | 3 175  | 27 654 | 5 660 |

Source: Norwegian Environment Agency

Historically, all lubricant was allocated to product group 201. From 1995 product group 204 and 206 were separated out, and from 1998 the remainder of 201 was split into the product groups 202, 203 and 295. Product groups 207 and 208, which were established in 2003, are reallocations of group 202 and 203.

| <b>Table 4.34 Lubricant product groups in the sales of petroleum statistics.</b> |                                            |
|----------------------------------------------------------------------------------|--------------------------------------------|
| Product group                                                                    | Product group (text)                       |
| 201                                                                              | Lubricants                                 |
| 202                                                                              | Auto motor and gear oil                    |
| 203                                                                              | Navigation and aviation motor and gear oil |
| 204                                                                              | Industrial lubricants                      |
| 205                                                                              | Hydraulic oils                             |
| 206                                                                              | Process and transformer oil                |
| 207                                                                              | Motor oil                                  |
| 208                                                                              | Gear oil                                   |

Source: Norwegian Environment Agency

The sales statistics does not distinguish between lubricant wax and lubricant oil, and hence the default average (tier 1) carbon content (CC) factor was used.

#### 4.5.1.4 Emission factors

##### ODU factors

The factors for oxidation during use (ODU) for all product groups 204 to 208 are shown in Table 4.35.

The factors were found by contacting a broad selection of users and purchasers of lubricant oils, as well as branch organisations and interest groups. We have here assumed that loss during use corresponds to oxidation during use, as described above. As the former product groups 201 – 203 are not covered in the report (Weholt et al. 2010), ODUs for these product groups were estimated. The ODU for product group 202 and 203 is simply the average of the ODUs for product number 207 and 208. For product group 201 the ODU in 1990 to 1994 was estimated as the weighted average of ODU for product group 202 to 206, based on sold amounts in 1998. In 1995 to 1997 it was estimated from product group 202, 203 and 205 in 1998.

| Table 4.35 Oxidation during use (ODU) factors. |            |        |
|------------------------------------------------|------------|--------|
| Product group                                  | ODU factor | Source |
| (L = literature, E = estimated)                |            |        |
| 201 (1990 to 1994)                             | 0.67       | E      |
| 201 (1995 to 1997)                             | 0.17       | E      |
| 202                                            | 0.175      | E      |
| 203                                            | 0.175      | E      |
| 204                                            | 0.75       | L      |
| 205                                            | 0.15       | L      |
| 206                                            | 0.90       | L      |
| 207                                            | 0.25       | L      |
| 208                                            | 0.10       | L      |

Source: Weholt et al. (2010)

The statistics on sold lubricant include oil combusted in two-stroke petrol engines, and hence considerations must be made to avoid double counting. However, the report (Weholt et al. 2010), which is quite detailed when describing the elaboration of ODU factors, does not mention consumption in two-stroke petrol engines. We therefore assume that consumption in two-stroke petrol engines is omitted in the ODU factors, and thus no correction for double counting is necessary.

### Other factors

The figures on sold lubricants are given in m<sup>3</sup> and must be converted to tonnes. The density varies between different lubricant types, and based on sources available on the Internet it is estimated to 0.85 m<sup>3</sup>/tonne as an average for all lubricant types, see Exxonmobile (2009) and Neste\_Oil (2014). The conversion from tonnes of consumed lubricant to tonnes of emitted CO<sub>2</sub> is performed based on IPCC default factors for energy content (NCV) and carbon content per unit of energy see [Table 4.36](#). This conversion method implicitly adjusts for the content of non-hydrocarbons. The amount of sold lubricants in ktonne is given in [Table 4.37](#).

**Table 4.36 Other factors.**

| Factor                    | Value  | Unit                  | Source       |
|---------------------------|--------|-----------------------|--------------|
| Density (d)               | 0.85   | m <sup>3</sup> /tonne | Producers    |
| Net calorific value (NCV) | 0.0402 | TJ/tonne              | IPCC 2006 GL |
| Carbon content (CC)       | 20     | Tonne C/TJ            | IPCC 2006 GL |

**Table 4.37 Sold amounts of lubricants, ktonnes.**

| Year | Sold amount lubricant |
|------|-----------------------|
| 1990 | 84.7                  |
| 1995 | 73.6                  |
| 2000 | 71.0                  |
| 2005 | 57.6                  |
| 2010 | 57.5                  |
| 2015 | 41.6                  |
| 2016 | 48.8                  |
| 2017 | 47.6                  |
| 2018 | 50.8                  |
| 2019 | 48.8                  |
| 2020 | 48.8                  |
| 2021 | 46.6                  |

Source: Statistics Norway



#### 4.5.1.5 *Uncertainties and time-series consistency*

The uncertainty in the estimated emissions from lubricant use (except in two-stroke petrol engines) is assumed to be rather low. The uncertainty in the activity data is assumed to be 5%, see Table 4.38, in line with the IPCC guidelines for countries with well-developed energy statistics. Also, the uncertainty of the carbon content is an IPCC default value, and the NCV uncertainty is assumed to be equally large. The uncertainty estimate for the density is based on an expert judgement of the available data on the Internet.

The uncertainty of the country specific ODU estimate is set much lower than for the IPCC default value. This is partly due to the thorough evaluation in the report (Weholt et al. 2010), and partly due to estimations based on the ODUs from this report combined with sales and waste collection statistics, which states that 85 to 90% of all waste lubricant oil is collected by Statistics Norway (Statistics Norway & SOE Norway 2014). This rather high collection percentage seems reasonable, due to a refund scheme for waste oil combined with strict control of the collected amounts. Higher ODUs would increase this percentage, and vice versa.

| Table 4.38 Uncertainty estimates (%). |             |
|---------------------------------------|-------------|
| Parameter                             | Uncertainty |
| Activity data (A)                     | 5           |
| Oxidation during use (ODU)            | 5           |
| Density (d)                           | 3           |
| Net calorific value (NCV)             | 3           |
| Carbon content (CC)                   | 3           |

Based on these uncertainties, the overall uncertainty of the emissions from lubricating oil (except from use in two-stroke petrol engines) is estimated at 20%.

The split of lubricants between different product groups in the activity data have varied throughout the time series, and the level of detail is lower at the beginning of the time series. This might potentially introduce some time series inconsistencies. However, this variation is taken into account for the used ODU factors, and no significant time series inconsistencies are thus expected.

#### 4.5.1.6 *Category-specific QA/QC and verification*

Emissions from lubricant use are calculated in Excel sheets before being included in the main model. Activity data for the calculations of emissions from lubricants are subject to checks for consistency compared to previous years. Major discrepancies are examined.

Periodically, sales statistics are compared to waste statistics as a quality control of level. In addition, the emission estimates are subject to the general QA/QC procedures (see chapter 1.2.3) when included in the main model.

#### **4.5.1.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.5.1.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.5.2 Paraffin wax use, 2D2**

#### **4.5.2.1 Category description**

Paraffin waxes are produced from crude oil and used in a number of different applications, including candles, tapers and the like. Combustion of such products results in emissions of fossil CO<sub>2</sub>. Emissions from the incineration of products containing paraffin wax, such as wax coated boxes, are covered by emissions estimates from waste incineration.

#### **4.5.2.2 Methodological issues**

Emissions of CO<sub>2</sub> from the burning of candles, tapers and the like are calculated using a modified version of equation 5.4 for Waxes – Tier 1 Method of the 2006 IPCC Guidelines:

$$(4.12) \text{ Emissions} = PC * PF * CC_{Wax} * 44/12$$

Where:

- Emissions = CO<sub>2</sub> emissions from waxes, tonne CO<sub>2</sub>
- PC = total candle consumption, TJ
- PF = fraction of candles made of paraffin waxes
- CC<sub>Wax</sub> = carbon content of paraffin wax (default), tonne C/TJ (Lower Heating Value basis)
- 44/12 = mass ratio of CO<sub>2</sub>/C

Consumption figures on paraffin waxes are multiplied by the default net calorific values (NCV). Net consumption in calorific value is then converted to carbon amount, using the value for carbon content (Lower Heating Value basis) and finally to CO<sub>2</sub> emissions, using the mass ratio of CO<sub>2</sub>/C.

#### **4.5.2.3 Activity data**

Statistics Norway collects data on import, export and sold produce of “Candles, tapers and the like (including night lights fitted with a float)”. Using these data, net consumption of paraffin waxes and other candle waxes (including stearin) can be calculated.

#### 4.5.2.4 Emission factors

Parameter values used in the emissions calculations are given in Table 4.39.

| Table 4.39 Parameters employed when calculating emissions. |        |                       |            |
|------------------------------------------------------------|--------|-----------------------|------------|
| Parameters                                                 | Factor | Unit                  | References |
| Net calorific value (NCV)                                  | 40.20  | TJ/Gg                 | 2006 IPCC  |
| Carbon content (CCWax, Lower Heating Value basis)          | 20.00  | tonnes C/TJ = kg C/GJ | 2006 IPCC  |
| Mass ratio of CO <sub>2</sub> /C                           | 3.67   | -                     |            |
| Fraction of paraffin wax (PF)                              | 0.66   | -                     |            |

The assumption of 0.66 as the fraction of all candles being made of paraffin waxes is based on estimates obtained from one major candle and wax importer (estimating ca. 0.5) and one Norwegian candle manufacturer (estimating ca 0.8). The importer estimated the fraction to be ca. 5% higher in 1990. However, since this possible change is considerably smaller than the difference between the two fraction estimates, we have chosen to set this factor constant for the whole time series. The fraction of paraffin waxes has probably varied during this period, as it, according to the importer, strongly depends on the price relation between paraffin wax and other, non-fossil waxes. However, at present we do not have any basis for incorporating such factor changes.

Furthermore, we assume that practically all of the candle wax is burned during use, so that emissions due to incineration of candle waste are negligible.

#### 4.5.2.5 Uncertainties and time-series consistency

According to the 2006 IPCC Guidelines, the default emission factors are highly uncertain. However, the default factor with the highest uncertainty is made redundant in our calculations, due to the level of detail of our activity data.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### 4.5.2.6 Category-specific QA/QC and verification

There is no specific QA/QC procedure for this sector. See Annex V for the description of the general QA/QC procedure.

#### 4.5.2.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

#### **4.5.2.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.5.3 Solvent use, 2D3a**

#### **4.5.3.1 Category description**

The use of solvents leads to emissions of non-methane volatile organic compounds (NMVOC) which is regarded as an indirect greenhouse gas. The NMVOC emissions will over a period of time in the atmosphere oxidize to CO<sub>2</sub>, which is included in the total greenhouse gas emissions reported to UNFCCC. As explained in chapter 9, the indirect CO<sub>2</sub> emissions from oxidized CH<sub>4</sub> and NMVOC are calculated from the content of fossil carbon in the compounds. The indirect emissions of CO<sub>2</sub> from 2D3a are reported in CRF table 6.

The calculated emissions from solvent use are sensitive to inter-annual changes in the activity data. Sudden changes in activity data will lead to peaks or reduction in the emissions. A further explanation is given in section 4.5.3.2. An illustration of inter annual changes is given in Figure 4-6.

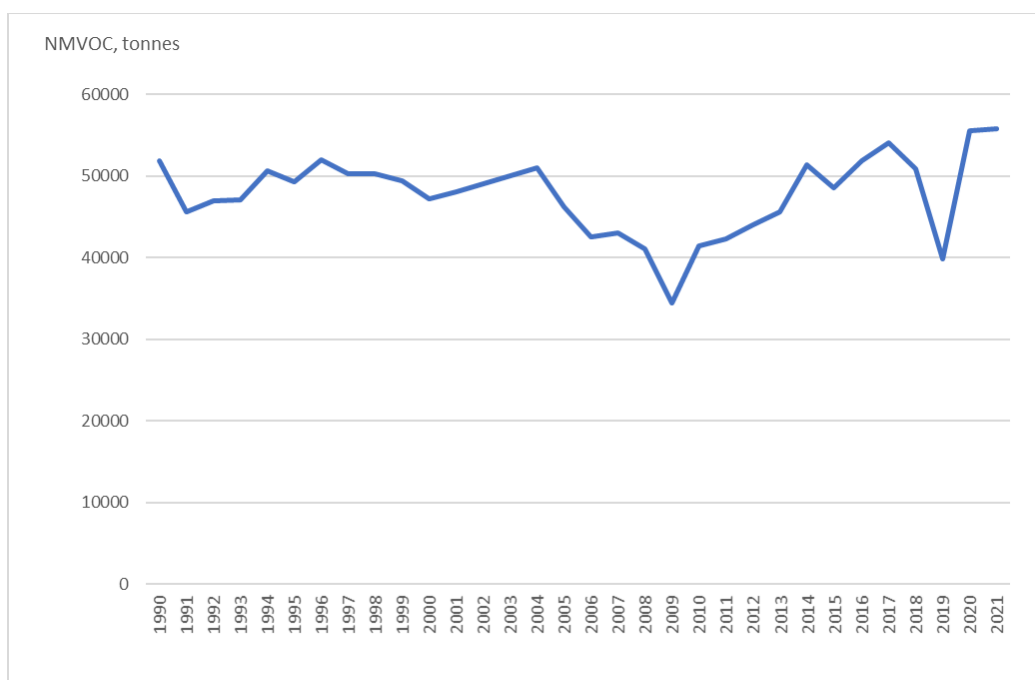


Figure 4-6 Emissions from solvent use illustrating inter-annual changes, emissions in tonnes NMVOC. Source: Statistics Norway

#### 4.5.3.2 Methodological issues

The general model used is a simplified version of the detailed methodology described in chapter 6 of the EMEP/CORINAIR Guidebook 2007 (EEA 2007). It represents a mass balance *per substance*, where emissions are calculated by multiplying relevant activity data with an emission factor. For better coverage, point sources reported from industries to the Norwegian Environment Agency and calculated emissions from a side model for cosmetics are added to the estimates. A detailed description of method and activity data is available in Holmengen and Kittilsen (2009).

It is assumed that all products are used the same year as they are registered, and substances are not assumed to accumulate in long-lived products. In other words, it is assumed that all emissions generated by the use of a given product during its lifetime take place in the same year as the product is declared to our data source, the Norwegian Product Register. In sum, this leads to emission estimates that do not fully reflect the actual emissions taking place in a given year and may lead to significant interannual changes in NMVOC emissions and hence indirect CO<sub>2</sub>. Emissions that in real life are spread out over

several years will for that reason all appear in the emission estimate for the year of registration. However, this systematic overestimation for a given year probably more or less compensates for emissions due to previously accumulated amounts not being included in the estimate figures.

No official definition of solvents exists, and a list of substances to be included in the inventory on NMVOC emissions was thus created. The substance list used in the Swedish NMVOC inventory (Skårman et al. 2006) was used as a basis. This substance list is based on the definition stated in the UNECE Guidelines<sup>14</sup>. The list is supplemented by NMVOC reported in the UK's National Atmospheric Emissions Inventory (AEA 2007). The resulting list was comprised by 678 substances. Of these, 355 were found in the Norwegian Product Register for one or more years in the period 2005-2007.

#### Cosmetics

Cosmetics are not subject to the duty of declaration. The side model is based on a study in 2004, when the Climate and Pollution Agency (now called Norwegian Environment Agency) calculated the consumption of pharmaceuticals and cosmetics (SFT 2005a). The consumption was calculated for product groups such as shaving products, hair dye, body lotions and antiperspirants. The consumption in tonnes each year is calculated by using the relationship between consumption in Norwegian kroner and in tonnes in 2004. Figures on VOC content and emission factors for each product group were taken for the most part from a study in the Netherlands (IVAM 2005), with some supplements from the previous Norwegian solvent balance (the previous NMVOC emission model).

#### **4.5.3.3 Activity data**

The main data source is the Norwegian Product Register. Data are usually received annually, but they can occasionally be available too late for the latest submission. This will, as well as updated information on specific chemicals, lead to recalculations.

Any person placing dangerous chemicals on the Norwegian market for professional or private use has a duty of declaration to the Product Register, and import, export and manufacturing is reported annually. The only exception is when the amount of a given product placed on the market by a given importer/producer is less than 100 kg per year.

The information pertained in the data from the Product Register makes it possible to analyse the activity data on a substance level, distributed over product types (given in UCN

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<sup>14</sup> "Volatile compound (VOC) shall mean any organic compound having at 293.15 degrees K a vapor pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use."

codes; Product Register 2007), industrial sectors (following standard industrial classification (NACE; Statistics Norway (2014b)), including private households (no NACE), or a combination of both. As a consequence, the identification of specific substances, products or industrial sectors that have a major influence on the emissions, is greatly facilitated.

#### Cosmetics

The side model for cosmetics is updated each year with data on from the Norwegian Association of Cosmetics, Toiletries and Fragrance Suppliers (KLF). The data are usually received in time for the annual calculations.

#### Point sources

Data from nine point sources provided by the Norwegian Environment Agency is added annually to the emissions estimates. The point sources are reported from the industrial sector "Manufacture of chemicals and chemical products" (NACE 24). To avoid double counting, NMVOC used as raw materials in this sector are excluded from the emission estimates from the Product Register data.

#### **4.5.3.4 Emission factors**

Emission factors are specific for combinations of product type and industrial sector. Emission factors are gathered from the Swedish model for estimating NMVOC emissions from solvent and other product use (Skårman et al. 2006). The emission factors take into account different application techniques, abating measures and alternative pathways of release (e.g., waste or water). These country-specific emission factors apply to 12 different industries or activities that correspond to sub-divisions of the four major emission source categories for solvents used in international reporting of air pollution (EEA 2007).

It is assumed that the factors developed for Sweden are representative for Norwegian conditions, as we at present have no reasons to believe that product types, patterns of use or abatement measures differ significantly between the two countries. Some adjustments in the Swedish emission factors were made when the model was first developed by Holmengen and Kittilsen (2009) and several improvements of single emissions factors have been made in the following years.

In accordance with the Swedish model, emission factors were set to zero for a few products that are assumed to be completely converted through combustion processes, such as EP-additives soldering agents and welding auxiliaries. Quantities that have not been registered to industrial sector or product type are given emission factor 0.95

(maximum). Emission factors may change over time, and such changes may be included in this model. However, all emission factors are considered constant for all years.

#### **4.5.3.5 *Uncertainties and time-series consistency***

##### Uncertainty in emission factors

The emission factors are more detailed in the new NMVOC model than in the previous model, as this model can take into account that emissions are different in different sectors and products, even when the substance is the same. However, for this to be correct, a thorough evaluation of each area of use is desirable, but not possible within a limited time frame. Thus, the emission factor is set with general evaluations, which leads to uncertainty.

The emission factors are gathered from several different sources, with different level of accuracy. The uncertainties in emission factors depend on how detailed assessment has been undertaken when the emission factor was established. Some emission factors are assumed to be unbiased, while others are set close to the expected maximum of the range of probable emission factors. This, together with the fact that the parameter range is limited, gives us a non-symmetrical confidence interval around some of the emission factors. For each emission factor we thus have two uncertainties: one negative (n) and one positive (p). These are aggregated separately, and the aggregated uncertainty is thus not necessarily symmetrical.

##### Uncertainty in activity data

For the activity data, the simplified declarations and the negative figures due to exports lead to known overestimations, for which the uncertainty to a large extent is known. A more elaborate problem in calculations of uncertainty is estimating the level of omissions in declaration for products where the duty of declaration does apply. In addition, while declarations with large, incorrect consumption figures are routinely identified during the QA/QC procedure, faulty declarations with small consumption figures will only occasionally be discovered. There is however no reason to believe that the Product Register data are more uncertain than the data source used in the previous model (statistics on production and external trade), as similar QA/QC routines are used for these statistics.

The errors in activity data are not directly quantifiable. Any under-coverage in the Product Register is not taken into account. The activity data from the Swedish Product register has an uncertainty of about 15% (Skårman et al. 2006). The Norwegian Product Register is assumed to be comparable to the Swedish, and thus the uncertainty in the activity data is assumed to be 15%. For some products, simplified declarations give an indication of maximum and minimum possible amounts. In these cases, the maximum amount is used,



and the positive uncertainty is set to 15% as for other activity data, while the negative uncertainty is assumed to be the interval between maximum and minimum amount. All activity data are set to zero if negative.

A detailed description of the uncertainty analysis is available in Holmengen and Kittilsen (2009). The variance of total emission was estimated from the variance estimates obtained for emission factors and activity data, using standard formulas for the variance of a sum and the variance of a product of independent random variables. The aggregated uncertainties in level and trend are given in [Table 4.40](#) and [Table 4.41](#).

**Table 4.40 Uncertainty estimates for level in NMVOC emissions, 2005-2007. Tonnes and%.**

| Uncertainty in level | Negative (n) | Negative (n) (% of total emissions) | Positive (p) | Positive (p) (% of total emissions) |
|----------------------|--------------|-------------------------------------|--------------|-------------------------------------|
| 2005                 | 2 288        | 4.58                                | 1 437        | 2.88                                |
| 2006                 | 1 651        | 3.70                                | 1 103        | 2.47                                |
| 2007                 | 1 299        | 2.79                                | 1 168        | 2.51                                |

**Table 4.41 Uncertainty estimates for trend in NMVOC emissions, 2005-2007. Tonnes.**

| Uncertainty in trend | Negative (n) | Positive (p) | 95% confidence interval for change |
|----------------------|--------------|--------------|------------------------------------|
| 2005-2006            | 2 135        | 1 067        | (-7 366, -4 164)                   |
| 2006-2007            | 1 420        | 947          | (407, 2 774)                       |
| 2005-2007            | 1 882        | 1 076        | (-5 286, -2 328)                   |

#### Time series consistency

The activity data from the Norwegian Product Register is only available from 2005 onwards. For the years from 1990 to 2000, data from the previous solvent balance has been used. The two time series have been spliced by interpolation. This introduces a degree of time series inconsistency. However, the results from the previous solvent balance were evaluated and updated with new knowledge from the current model in Holmengen and Kittilsen (2009). Thus, overall time series consistency is deemed to be satisfactory.

#### **4.5.3.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V. Large between-year discrepancies in the time series of substance quantities are routinely identified and investigated, to correct errors in consumption figures. Large within-year discrepancies between minimum and

maximum quantities in simplified declarations are routinely identified and investigated, to prevent overestimation for substances where consumption figures are given in intervals. Large within-year discrepancies between totals for industrial sectors (NACE) and totals for products (UCN) are routinely identified and investigated, to detect erroneous or incomplete industrial sectoral and product type distribution.

#### **4.5.3.7 Category-specific recalculations**

Reallocation: Indirect emissions of CO<sub>2</sub> from emissions of NMVOC are now reported separately in CRF Table 6.

#### **4.5.3.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.5.4 Road paving with asphalt, 2D3b**

#### **4.5.4.1 Category description**

Indirect CO<sub>2</sub> emissions from NMVOC emissions from road paving with asphalt are reported in CRF table 6.

#### **4.5.4.2 Methodological issues**

The emissions from road paving are calculated in accordance with a Tier 1 approach (EEA 2013).

$$E_{\text{pollutant}} = AR_{\text{production}} * EF_{\text{pollutant}}$$

where

E pollutant = the emission of the specified pollutant

AR production = the activity rate for the road paving with asphalt

EF pollutant = the emission factor for this pollutant

#### **4.5.4.3 Activity data**

The activity data used is the annual weight of asphalt used for road paving in Norway, collected by the Contractors Association - Building and Construction annually (EBA 2014).

#### **4.5.4.4 Emission factors**

The share of bitumen in the asphalt is set to be 0.05 for all years, based on information from a road technology Institute, a centre for research and development, quality control and documentation of asphalt (<http://www.asfaltteknisk.no/>). The emissions of NMVOC are calculated using an emission factor of 16 g NMVOC / tonne asphalt (EEA 2013).

#### 4.5.4.5 *Uncertainties and time series consistency*

The activity data and emission factor used are uncertain. The annual emissions are however low. Activity data on asphalt used are available from 1995 onwards. For the years 1990-1994, the emission figure for 1995 is used. This introduces some degree of time series inconsistency in methodology. The annual variability in emissions throughout the entire time series is however insignificant, and this inconsistency is thus deemed acceptable.

#### 4.5.4.6 *Category-specific QA/QC and verification*

There is no source specific QA/QC procedure for this sector. See Annex V for the description of the general QA/QC procedure.

#### 4.5.4.7 *Category-specific recalculations*

*Reallocation:* Indirect emissions of CO<sub>2</sub> from emissions of NMVOC are now reported separately in CRF Table 6.

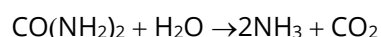
#### 4.5.4.8 *Category-specific planned improvements*

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 4.5.5 *Other, 2D3d (use of urea as a reductant)*

#### 4.5.5.1 *Category description*

Urea is used in selective catalytic reduction (SCR) to reduce NO<sub>x</sub> emissions, in Norway primarily from road transport and shipping. When urea is injected upstream of a hydrolysis catalyst in the exhaust line, the following reaction takes place:



The ammonia formed by this reaction is the primary agent that reacts with nitrogen oxides to reduce them to nitrogen.

There were no emissions from the use of urea in SCR in 1990, and the use of urea and thus emissions have increased significantly the last few years. 2D3d is not a key category.

#### 4.5.5.2 *Methodological issues*

Emissions are calculated based on equation 3.2.2 of Volume 2 of the 2006 IPCC Guidelines:

$$\text{Emissions} = \text{Activity} * 12/60 * \text{Purity} * 44/12$$

where

Emissions = CO<sub>2</sub> emissions from urea-based additive in catalytic converters (Gg CO<sub>2</sub>)

Activity = amount of urea-based additive consumed for use in catalytic converters

Purity = the mass fraction (= fraction of urea in the urea-based additive)

The fraction 12/60 converts the emission figure from urea ( $\text{CO}(\text{NH}_2)_2$ ) to carbon (C), while 44/12 converts C to  $\text{CO}_2$ .

Emissions are calculated as the sum of emissions from each purity.

#### **4.5.5.3 Activity data**

No official statistics cover sale, production, or use of urea in SCR in Norway. There is no national production of urea used in SCR, as the urea produced in Norway is used for fertilizers only. There are many importers of urea used in SCR, and the urea is often imported in smaller containers, and not in bulk. Information from the largest importer of urea shows that urea is imported to Norway in at least three different purities: 32.5% for use in road transport, 40% for use in shipping, and 100% for dilution before use. The statistics on external trade does not have a clear split on urea used for fertilizers and urea used in SCR, nor does it split on different purities.

Based on these considerations, import data from the largest producer together with estimates of marked shares have been used to calculate the total consumption of urea used in SCR each year. The first year of activity set at 2008, as very few vehicles had the technology prior to this year.

#### **4.5.5.4 Emission factors**

There are no emission factors used for this calculation. All carbon in the urea used is converted to  $\text{CO}_2$ .

#### **4.5.5.5 Uncertainties and time series consistency**

There are no emission factors as such in these calculations, and the purity of the different solutions are deemed to be reliable. However, the calculations are based on activity data where expert judgement is an important parameter, and there is a certain degree of uncertainty.

The same source of activity data and the same parameters have been used for all years, and the time series consistency is thus deemed to be satisfactory.

#### **4.5.5.6 Category-specific QA/QC and verification**

In the development of the emission estimates, activity data used (import data from the largest importer) were compared with import data from the statistics on external trade.

#### **4.5.5.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.5.5.8 *Category-specific planned improvements***

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 4.6 Electronics industry – 2E

Norway reports the source category integrated circuit or semiconductor under the category 2E, see [Table 4.42](#) and [Table 4.43](#).

**Table 4.42 Electronics industry. Components emitted and included in the Norwegian inventory.**

| Source category                          | SF <sub>6</sub> | HFCs | PFCs | NF <sub>3</sub> | Tier | Key category |
|------------------------------------------|-----------------|------|------|-----------------|------|--------------|
| 2E1. Integrated circuit or semiconductor | E               | NO   | NO   | NO              | 1    | No           |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occuring. IE = Included Elsewhere.*

**Table 4.43 Emission trends for 2E Electronics industry (t CO<sub>2</sub> equivalents).**

| Source category                          | 1990 | 1990, % of IPPU | 2020  | 2021  | 2021, % of IPPU | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
|------------------------------------------|------|-----------------|-------|-------|-----------------|---------------------|---------------------|
| 2E1. Integrated circuit or semiconductor | 0    | 0.0             | 1 175 | 1 175 | 0.0             | NA                  | 0.0                 |

*Source: Statistics Norway Norwegian Environment Agency*

### 4.6.1 Integrated circuit or semiconductor, 2E1

#### 4.6.1.1 Category description

There are SF<sub>6</sub> emissions from the use in the manufacturing of semiconductors. There were no emissions from the production of integrated circuit or semiconductors in 1990, but the emissions in 2019 were 1 140 tonnes of CO<sub>2</sub>-equivalents, see [Table 4.43](#).

#### 4.6.1.2 Methodological issues

The method is described in a report from SFT (1999c) and there have been emissions of SF<sub>6</sub> from this source since 1995. Data on sales to semiconductor manufacturers were collected for 1998, and total sales amounted to 90 kg. The report projected that sales would increase to 100 kg but would then remain in that range in the next decade. No new data have been collected, and the projection from the 1999 report has been prolonged.

#### 4.6.1.3 Activity data

The report from 1999 assumed that 50% of the gas reacts in the etching process and the remaining 50% are emitted. Hence 45 kg are reported as emissions until 1998 and 50 kg from 1999 onwards.

#### 4.6.1.4 Emission factors

The leakage rate for the production of semiconductors is shown in [Table 4.44](#).

**Table 4.44 Annual rate of leakage of SF<sub>6</sub> from the production of semiconductors.**

| Emission source              | Leakage rate (% of input of SF <sub>6</sub> ) |
|------------------------------|-----------------------------------------------|
| Production of semiconductors | 50                                            |

Source: SFT (1999c)

#### **4.6.1.5 Uncertainties and time series consistency**

An uncertainty estimate is given in Annex II.

A general assessment of the time series consistency has not revealed any time series inconsistencies in the emission estimates for this source category.

#### **4.6.1.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V. Since the emissions have been assumed to be constant since 1999, there is no specific QA/QC procedure for this source category.

#### **4.6.1.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.6.1.8 Category-specific planned improvements**

We are seeking to obtain updated information on the use of SF<sub>6</sub> in the production of semiconductors in Norway. The results from the mapping will hopefully contribute to better data quality and documentation for this source category.

## 4.7 Product uses as substitutes for ODS – 2F (key category for HFCs)

Norway reports the source category HFCs and PFCs from refrigeration and air conditioning and other applications under the category 2F. See [Table 4.45](#) and [Table 4.46](#) for details.

**Table 4.45 Product uses as substitutes for ODS. Components included in the inventory, tier of method and key category.**

| Source category                                                                                                            | HFCs | PFCs | SF <sub>6</sub> | NF <sub>3</sub> | Tier | Key category |
|----------------------------------------------------------------------------------------------------------------------------|------|------|-----------------|-----------------|------|--------------|
| 2F1-2F6. Refrigeration and air conditioning, foam blowing agents, fire protection, aerosols, solvents, other applications. | E    | E    | NO              | NO              | *    | Yes**        |

*\*Mainly estimated using Tier 2a (emissions calculated at a disaggregated level, emission factor approach).*

*Exceptions are mobile air conditioning that is estimated using Tier 2b (b=mass balance approach) and fire protection, aerosols and solvents that are estimated using Tier 1a (emissions calculated at an aggregated level, emission factor approach).*

*\*\*In the key category analysis, 2F1 and 2F6 have been aggregated.*

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occurring. IE = Included Elsewhere.*

**Table 4.46 Emission trends for 2F Product uses as substitutes for ODS (t CO<sub>2</sub> equivalents).**

| Source category                                                                        | 1990 | 1990, % of IPPU | 2020    | 2021    | 2021, % of IPPU | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
|----------------------------------------------------------------------------------------|------|-----------------|---------|---------|-----------------|---------------------|---------------------|
| 2F1. Refrigeration and air conditioning                                                | 49   | 0.0             | 711 582 | 605 531 | 6.7             | 1239420.7           | -14.9               |
| 2F2-2F6. Foam blowing agents, fire protection, aerosols, solvents, other applications. | 0    | 0.0             | 38 215  | 22 892  | 0.3             | NA                  | -40.1               |
| 2F. Total                                                                              | 49   | 0.0             | 749 797 | 628 423 | 7.0             | 1286245.5           | -16.2               |

*Source: Statistics Norway and Norwegian Environment Agency*

[Table 4.46](#) shows the emission trends for 2F. The GHG emissions from this sector category were about 0.6 million tons in 2021, this is 7.0 per cent of the total emission from the IPPU-sector. The emissions in 1990 were insignificant (49 tonnes CO<sub>2</sub> equivalents) but have increased substantially over the years. The emissions decreased by 16.2 per cent from 2020 to 2021. This decrease was mainly caused by reduced emissions in 2.F.1.a, Commercial refrigeration, which decreased by 43 ktonnes CO<sub>2</sub> equivalents from 2020 to



2021, corresponding to a decrease of 25 per cent. There was also a relatively high reduction in 2.F.1.e and 2.F.1.f by 30 and 27 ktonnes CO<sub>2</sub> equivalents. The decrease in 2.F.1.d Transport refrigeration commented in the previous submission continued in 2021 with a reduction of 7 ktonnes, corresponding to 37.5 per cent reduction in this sector from 2020 to 2021. The recent and rapid decline of emissions in these sectors was mainly a consequence of restrictions from the EU F-gas regulation (implemented in Norway) in combination with equipment that reached its end of life in 2021.

The majority of the emissions are reported in 2F1 and these include minor emissions of PFC-218 in the years 2010-2014.

HFCs and PFCs are mainly used as substitutes for ozone depleting substances (CFCs and HCFCs) that are being phased out according to the Montreal Protocol. They are used in varied applications, including refrigeration and air conditioning equipment, as well as in foam blowing, fire extinguishers, aerosol propellants and analysing purposes. There is no production of HFCs and PFCs in Norway. However, PFCs are emitted as a by-product during the production of aluminium. Due to, high taxation, the use of PFCs in product-applications has been very low. PFC-218 has been used as a commercial cooling agent.

The amounts of imported and exported gases are found in registers from the Norwegian Directorate of Customs and Excise. All import of HFC and PFC -gases are covered in these registers, as Norway lays a tax on the import of HFC and PFC-gases (Ministry of Finance 2014). In January 2003 a tax on import and production of HFC and PFC was introduced at NOK 180 per tonne CO<sub>2</sub> equivalents. In July 2004 this tax was supplemented with a refund for the destruction of used gas. The tax has increased over the years and stands in 2022 at NOK 766 (approximately EUR 78) per tonne CO<sub>2</sub> equivalents of gas imported. In May 2010, EU regulation (EC) No 842/2006 on certain fluorinated greenhouse gases was implemented in Norwegian legislation, and the revised EU regulation (EU) No 517/2014 with some adjustments was implemented in December 2018. At the same time, a licensing system for import and export, including a phase down scheme for HFC in bulk, according to the requirements in the Kigali Amendment to the Montreal Protocol, were implemented in the national legislation.

In addition, practically all export of F-gases is covered, as commodities with F-gases have their own commodity code (HS-code). The registered export of F-gases from Norway is very low, and any underestimation of the export of F-gases would thus be very slight and eventually lead to over-estimation (and not under-estimation) of the emissions.

The imported and exported gases are allocated to sectors based on commodity codes and information identifying each company. In some cases (sector 2F1) the type of gas is used as additional information. Uncertainties in the distribution by sector do not affect the total amount of F-gases to be emitted over time, as the emissions over time are determined by the total amount of F-gases to be distributed. Thus, under-estimation in one sector would eventually lead to an equivalent over-estimation in another sector at some point of time.

The HFC emissions from 2F1 and 2F6 is defined as a key category according to both the approach 1 and the approach 2 analysis.

#### **4.7.1 Refrigeration and air conditioning, 2F1**

##### **4.7.1.1 Category description**

HFCs and PFCs are mainly used as substitutes for ozone depleting substances (CFCs and HCFCs) that are being phased out according to the Montreal Protocol. Emissions from refrigeration and air conditioning equipment are reported under this source category.

The calculated emissions in 2F1 are sensitive to inter-annual changes in the activity data. Sudden changes due to for example new legislation will lead to peaks or reduction in the emissions. An illustration of this is given in Figure 4-7.

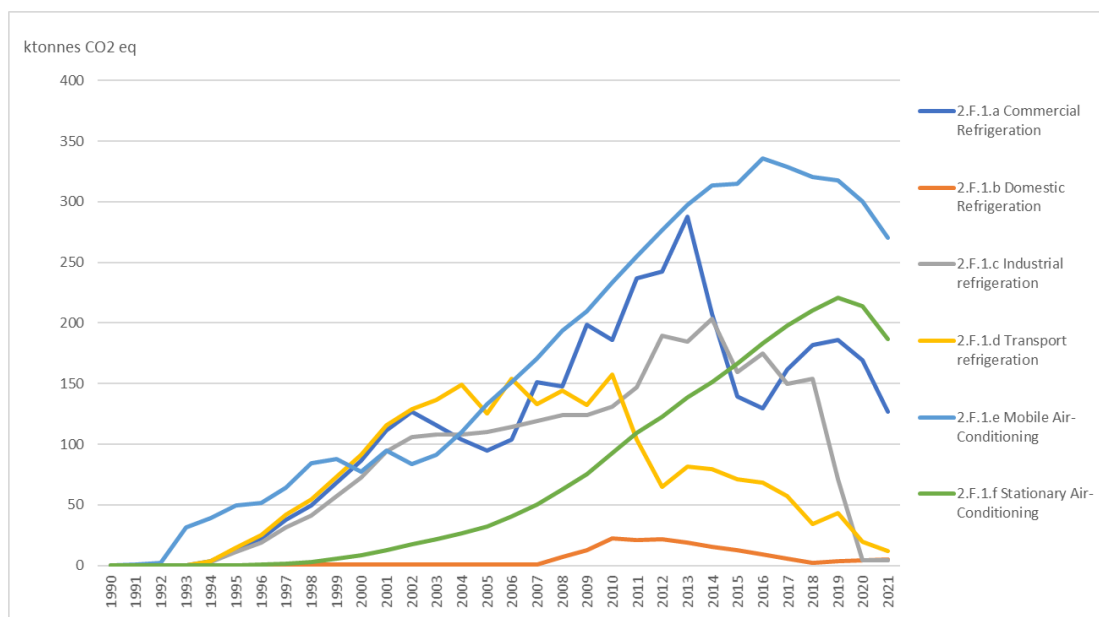


Figure 4-7 Emissions in the 2F1 sectors illustrating inter-annual changes, emissions in ktonnes CO<sub>2</sub> equivalents. Source: Statistics Norway

As seen in the figure above there is a reduction in emissions in 2.F.1.a and 2.F.1.d in the years around 2003-2005. This reduction is a result of the tax on F-gas implemented in 2003, leading to reduced bulk imports in the following years.

In 2.F.1.d transport refrigeration the emissions are stable up until 2010. At this stage the emissions are falling due to reduced imports in early 2000's and that the equipment reaches end of life around 2010. The same effect can be seen in 2.F.1.a commercial refrigeration between 2013 and 2015. The reduced imports in 2003 results in an abrupt decrease in emissions when the equipment reaches end of life. The emissions increase again in 2016-2018 as imports are normalizing again for a period from 2005.

In 2.F.1.c industrial refrigeration, there is a reduction of emissions between 2014 and 2015. This reduction continues in the following years. The reason can be found in the tax implemented in 2003, leading to a decrease in new equipment from this year. Bulk imports from 2003 and onwards are mainly used to refill existing equipment.

The decrease in emissions from 2016 to 2020 in 2.F.1.e Mobile Air-Conditioning is due to the EU MAC-directive and the following restriction stating that from January 1st 2017,

registration, sales and use of new vehicles with air-condition equipment constructed for fluor containing cooling agents with a GWP value of 150 or higher, is prohibited. The emissions in 2.F1.c, Industrial refrigeration, have decreased rapidly from 2018 to 2020. The sector reached a peak in emissions in 2014 and was slowly reducing its emissions up until 2018. Over the next two years, 2019 and 2020, we can see a drop in the emissions. This drop corresponded directly to the introduction of a tax in 2003 which aimed at stimulating a reduction in the use of HFCs. The tax resulted in a sharp decline in imports in 2003, and if we combine this with an assumed lifetime of 17 years for industrial refrigeration equipment, the result is the previously referred drop in emissions.

The decline of emissions in 2F from 2019 can also be seen in connection with the implementation of the restrictions from the EU F-gas regulation (implemented in 2018) which includes restrictions on refrigeration equipment that contains HFCs with GWP of 2500 and restricts the use of HFC refrigerants with GWP of 2500 or more for servicing and maintenance of refrigeration equipment.

#### **4.7.1.2 Methodological issues**

There is a good access to information regarding the use of HFCs and PFCs in Norway due to strict regulation and legislation. This provides a solid base of activity data from import and recovery (further described in 4.7.1.3). Actual emissions of HFCs and PFCs are hence calculated using the Tier 2 methodology as the input data and emission factors are country specific. This methodology takes into account the time lag in emissions from long lived sources, such as refrigerators and air-conditioning equipment. The chemicals slowly leak out from seams and ruptures during the lifetime of the equipment. The emissions are hence calculated for three different phases: when the equipment is being produced (filled for the first time), when the product is in regular use and when the product reach its end of life cycle. The leakage rate, or emission factor, varies considerably depending on type of equipment and its maintenance. Figure 4-8 illustrates the life cycle of a product containing fluorinated substances and the flow of chemicals between the three phases.

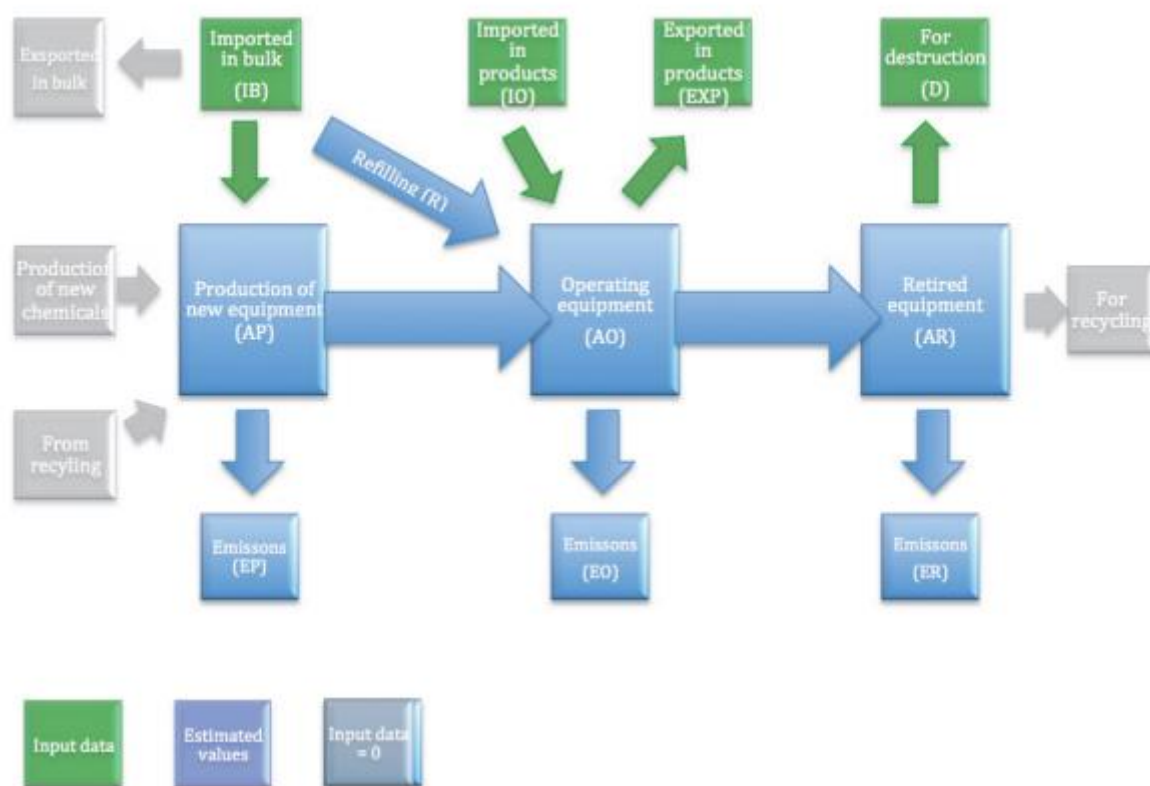


Figure 4-8 The three phases in a product's life cycle and the flow of chemicals in and out of the phases.

The total emission for each year (y), application category (a) and type of chemical (c) is calculated as follows:

$$E_{y,a,c} = EP_{y,a,c} + EO_{y,a,c} + ER_{y,a,c}$$

*EP* = Emissions from production of new equipment

*EO* = Emissions from operating equipment (equipment in use)

*ER* = Emissions from retired equipment

The calculation of emissions differs somewhat between the different source categories.

Table 4.47 gives an overview of the source categories and the different assumptions that are used for each subcategory considering production of new equipment and refilling of equipment in use.

| Table 4.47 Overview of source categories, HFC's and assumptions on production and refilling.* |                                       |                               |                                           |                                                 |
|-----------------------------------------------------------------------------------------------|---------------------------------------|-------------------------------|-------------------------------------------|-------------------------------------------------|
| Source category                                                                               | Production of new equipment in Norway | Refilling of equipment in use | Application category                      | HFC                                             |
| 2.F.1.a. Commercial Refrigeration                                                             |                                       |                               | Stand-alone Commercial Applications       | 23, 32, 125, 134a and 143a                      |
|                                                                                               | X                                     | X                             | Medium and Large Commercial Refrigeration | 23, 32, 125, 134, 134a, 143, 143a, 152a and 218 |
| 2.F.1.b Domestic Refrigeration                                                                |                                       |                               |                                           | 32, 125, 134a and 143a                          |
| 2.F.1.c Industrial Refrigeration                                                              | X                                     | X                             |                                           | 125, 134a and 143a                              |
| 2.F.1.d Transport Refrigeration                                                               | X                                     | X                             |                                           | 23, 125, 134, 134a, 143a and 227ea              |
| 2.F.1.e Mobile Air-Conditioning                                                               |                                       | X                             |                                           | 125, 134a and 143a                              |
| 2.F.1.f Stationary Air-Conditioning                                                           | X                                     | X                             |                                           | 23, 32, 125, 134a and 143a                      |
| 2F6 Other                                                                                     | X                                     | X                             | Fire extinguishers                        | 125, 134a and 227ea                             |
|                                                                                               | X                                     |                               | Foam                                      | 23, 134a and 152a                               |
|                                                                                               |                                       |                               | Aerosols: inhalators                      | 134a                                            |
|                                                                                               |                                       |                               | Aerosols: other                           | 134a and 152a                                   |
|                                                                                               |                                       |                               | Solvents                                  | 134a and 152a                                   |

\* Applications in all product groups may be imported

Emissions from almost all categories are calculated by using an emission factor approach. One exception is mobile air conditioning. For mobile air conditioning a hybrid of mass-balance and emission factor approach is used. There is no production of new cars in Norway; hence it is assumed that HFCs imported in bulk for use in mobile air conditioning is used to refill the systems after leakage. This is the mass-balance approach, and it leads to very high product life factors (up to 100%) in the beginning of the time series because no bank of chemicals was yet accumulated. A restriction is however set in the model: where the imported bulk is lower than 10% of the bank, the emission factor approach is applied.

This model assumption means that the product life factor will never be lower than 10 (using an emission factor of 10%) and is occurring towards the end of the time series.

### **Emissions from production of new equipment in Norway**

When HFCs and PFCs are imported as chemicals in bulk to Norway, they can either be used for production of new equipment, or they can be used for refilling of equipment already in use. Medium and large refrigeration equipments for supermarkets are, for instance, typically built and filled on site. Foam blowing, where HFCs are used in the process of making construction materials, is another example of production of new “equipment” taking place in Norway.

The emissions for all production activities are calculated by applying emission factors to the amount of chemicals used for new production that year, see [Table 4.48](#). The emission factors are within the range of factors recommended by the IPCC 2006 Guidelines.

$$EP_{y,a,c} = AP_{y,a,c} \cdot EFP_a$$

*EP = Emissions from production of new equipment*

*AP = Amount of chemical for production of new equipment*

*EFP = Emission Factor (leakage rate) for production of new equipment*

*y = year*

*a = application*

*c = chemical*

### **Emissions from equipment in use**

When products containing HFCs and PFCs are in use, the chemicals will gradually leak out through seams and holes in the equipment. Some products are sealed units with typically low leakage rates, and they are not refilled with new chemicals throughout their lifetime. Refrigerators and freezers used in households are examples of such equipment. As the chemicals leak out the equipment will gradually lose efficiency and eventually be decommissioned and replaced by new equipment. Larger equipment, for instance air conditioning equipment in office buildings or refrigeration systems in supermarkets, are refilled to keep up the efficiency throughout its operating lifetime. In all cases, as the chemicals are only gradually released, there will be a build-up of “bank”, i.e. the chemicals imported will accumulate in operating products and be emitted gradually depending on the leakage rate of the equipment.

These differences between the types of products lead to three different calculations of emission from equipment in use:

|                                                                      |                                                                                   |
|----------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Application categories without refilling:                            | $EO_{y,a,c} = EO_{y-1,a,c} + AON_{y,a,c} \cdot EFO_a - AON_{y-1,a,c} \cdot EFO_a$ |
| Mobile air conditioning (with refilling):                            | $EO_{y,a,c} = \text{MAX} (IB_{y,a,c}; AO_{y(31.12),a,c} \cdot EFO_a)$             |
| Other application categories with refilling:                         | $EO_{y,a,c} = AO_{y(31.12),a,c} \cdot EFO_a$                                      |
| $AON_{y,a,c} = (IB_{y,a,c} - EP_{y,a,c} + IO_{y,a,c} + EXO_{y,a,c})$ |                                                                                   |

EP = Emissions from production of new equipment

EO = Emissions from operation equipment (equipment in use)

EFO = Emission Factor (leakage rate) for operating equipment

AO = Amount of chemical in operating equipment

AON = Amount of chemicals in operation equipment which is new of the year

IB = Amount of chemicals imported in bulk

IO = Amount of chemicals imported in products

EXO = Amount of chemicals exported in products

It = lifetime (years)

y = year

a = application

c = chemical

In the CRF, there are reported amounts of HFC-143 in 2005 and 2006 and of HFC-134 in 2004 and 2008 filled into new manufactured products in commercial refrigeration. According to an expert on refrigeration and HFCs, these two gases are not used regularly in Norway, but is imported to be used in equipment testing. For other years, NO is therefore considered to be the appropriate notation key for these two gases for amounts filled into new manufactured products. This is confirmed by our data, and any new import of these two gases will be reflected in the registers from the Norwegian Directorate of Customs and Excise as both gases are covered by the tax on HFCs.

The reported stock emissions for perfluoropropane (C3F8) consumed in commercial refrigeration in CRF table 2(II).B-H have a declining trend. The use of PFCs is being phased out and replaced by other gases and only small amounts of PFCs have been imported in bulk in the last few years. About the same amount of PFCs that are reported as imported are reported as collected for destruction, so there has not been a build-up of stock that would generate emissions (i.e., the entire amount of gas remained in stock from the



previous year is assumed to be collected for destruction). Since 2014, the AD for annual average stock and stock emissions for C3F8 are therefore reported as “NO”.

A more thorough description of the methodology is available in Bjønnes (2013).

#### 4.7.1.3 Activity data

There is no production of HFC or PFC in Norway. Hence all emissions of these chemicals originate from chemicals imported in bulk or in products. The methodology requires that annual imported amounts of each chemical are obtained by source category. Various data sources are used: Amounts of chemicals imported in bulk were up to 2009 obtained from the Norwegian Climate and Pollution Agency (now Norwegian Environment Agency). After 2009, bulk data are collected from the Norwegian Directorate of Customs and Excise. Time series for imported and exported amounts of chemicals in products are based on collected data for some years and data prior to and between these years are estimated. For the years 1995-1997 data were collected through a survey performed in 1999 (SFT 1999b). Data on imports were collected from customs statistics for the years 2005-2006 and 2010-2012.

After 2011 the import data has been collected annually from The Norwegian Directorate of Customs and Excise (TAD) through two declaration systems named “TVINN” and “AFS”. The information from the two data bases is combined in order to get figures on total imported amounts of chemicals. In brief, the TVINN register provides information about type of chemical and whether it is imported in bulk or in a product. When imported as bulk, the amount is allocated to an application category based on the name of the importer and type of chemical or blend of chemicals. When imported in a product, the amount is allocated to an application category based on its classification according to the Harmonised System (HS8). This is an international system for classification of goods developed by the World Customs Organization.

The AFS register does not contain information about the classification of imported products, hence the amount of chemical is allocated to an application category based on the name of the importer and type of chemical or blend of chemicals. Information from TVINN is used by Statistics Norway in producing foreign trade statistics and is therefore readily accessible for use in the emission estimates. The following information is drawn from the data base once a year (for the year  $n-1$ ):

- Year of import
- Tax rate
- Tax amount
- Product type (according to the international system for classification of goods “HS”)

- Importer (name and business register number) (Bjønnes (2013))

Information from AFS is sent to Statistics Norway once a year (for the year n-1), specifically for the emission calculations:

- Year of import
- Tax rate group
- Tax amount
- Importer (name and business register number)

Statistics Norway receives information on amounts of fluorinated gas destructed each year from the company in charge of the collection. Before destruction, the gas is analysed to ensure accuracy of amounts and components in the gas. This detailed information is available because Norway has a refund for the tax for F-gas delivered to destruction. It is assumed that all gas that is delivered to destruction in Norway is delivered through this scheme as it is a large financial benefit. The gas destructed contains F-gas removed from refrigeration systems at end of life. In some sectors the industry has started phasing out equipment earlier than expected for the sector. This can result in that the amount of destructed gas being larger than the calculated amount remaining in products at decommissioning. In such cases, the extra amount of destructed F-gas will reduce the corresponding stock accordingly.

The information on the gas destructed is received as amounts of each gas in total. Hence, no detailed information about the application categories from which the chemicals are collected, is available. Since the origin of the chemicals is not tracked, the amounts destructed is allocated to application categories based on the calculated amounts of F-gas remaining in products at decommissioning in each of the sectors commercial refrigeration, industrial refrigeration, transport refrigeration, mobile AC, and stationary refrigeration. At the moment it is not assumed that F-gas from standalone commercial and domestic refrigeration is included in the destructed amounts.

A more thorough description of the activity data is available in Bjønnes (2013).

#### **4.7.1.4 Emission factors**

The emission factors used in the calculations are shown in Table 4.48.

| <b>Table 4.48 Emission factors* for HFCs and PFCs from 2F1 Refrigeration and Air conditioning.</b> |                  |                              |                             |                       |                              |
|----------------------------------------------------------------------------------------------------|------------------|------------------------------|-----------------------------|-----------------------|------------------------------|
| Source category                                                                                    | Lifetime (years) | Initial emission (%)         | Operating emission (%)      | Recovery Efficiency** | Initial charge remaining (%) |
| 2.F.1.a. Commercial Refrigeration                                                                  |                  |                              |                             |                       |                              |
| Stand-alone Commercial Applications                                                                | 10               | NO                           | 3.5                         | 0                     | 65                           |
| Medium/Large Commercial Refrigeration                                                              | 12               | 2 (1990-2003)<br>0.5 (2004-) | 10 (1990-2002)<br>4 (2008-) | NE                    | 80                           |
| 2.F.1.b Domestic Refrigeration                                                                     | 15               | NO                           | 0.5                         | 0                     | 92.5                         |
| 2.F.1.c Industrial Refrigeration                                                                   | 17               | 2                            | 10                          | NE                    | 80                           |
| 2.F.1.d Transport Refrigeration                                                                    | 9                | 1                            | 20                          | NE                    | 100                          |
| 2.F.1.e Mobile AC                                                                                  | 12               | NO                           | 10                          | 50                    | 60                           |
| 2.F.1.f Stationary AC                                                                              | 18               | 1 (1990-1999)<br>0.2 (2000-) | 4                           | NE                    | 80                           |

\*IPCC (2006)

\*\*In sources where Norway only use reported figures of destructed F-gas, recovery efficiency is reported as NE

### 2.F.1.a Commercial refrigeration

It is important to note that sub-application 2.F.1.a, Commercial refrigeration, is calculated at a more detailed level. Two groups of equipment that differs substantially in their life cycle and emission patterns, and hence emission factors, are taken into account:

- Stand-alone commercial applications include equipment like vending machines and moveable refrigerators and freezers typically used for keeping beverages and ice cream cold in supermarkets, office buildings, schools etc. There is currently no production of this kind of equipment in Norway. All emissions take place during the operating phase (emissions from stocks/lifetime emissions) or at decommissioning. The IPCC 2006 Guidelines recommends an operation emission factor between 1 and 15% for this application category, and between 0.1 and 0.5% for domestic refrigeration. Because the units imported to Norway are small, sealed units and thus similar to the refrigerators and freezers for domestic use, an emission factor in the lower end of IPCCs recommendation is believed to best reflect the actual emissions.

- Medium and large commercial refrigeration equipment are normally built and filled with fluorinated substances on site. They will thus have emissions both in the production phase and from operation/use the subsequent years. The IPCC 2006 Guidelines recommends an operation emission factor between 10 and 35% for this application category. In the 2021-submission it has been found grounds to differentiate this factor through the timeseries. The lower emission factor is used in the period of 1990-2002. The reasoning behind this is that the tax on imports of fluorinated substances is assumed to result in a high level of maintenance of the equipment and low leakage rates. Information from the industry has revealed that an emission factor of 10% is too high and that it is reasonable to say that the Norwegian users have an emission factor of 4% emission from 2008. There has been a linear interpolation of the emission factor between 2002 and 2008. In the 2021-submission it was also found reason to differ the emission factor for initial emissions. According to the industry the emissions connected to new installations fell to 0.5% in connection to the implementation of tax on F-gas.

#### 2.F.1.b Domestic Refrigeration

Emission factors used in the calculations for domestic refrigeration are found within the ranges defined by the IPCC guidelines. There is currently no production of this kind of equipment in Norway. All emissions take place during the operating phase (emissions from stocks/lifetime emissions) or at decommissioning. The emission factor for leakage is chosen in the lower end of IPCCs recommendation is believed to best reflect the actual emissions. The recovery efficiency from the domestic sector is unclear, and the recovery efficiency is hence chosen to be low. This is currently being revised in collaboration with the waste industry.

#### 2.F.1.c Industrial Refrigeration

In the industrial refrigeration sector, there is a relatively good knowledge of the various emission factors. The factors for lifetime, initial emission, operational emission, and initial charge remaining are chosen after input from the industry. For information on the calculation of recovery, please see description in section 4.7.1.3.

#### 2.F.1.d Transport

The emission factors for lifetime and initial emission are chosen in the higher end of the recommended range. It is assumed that the equipment has a long lifetime, and that during its lifetime has an annual leakage around 20%. The initial charge remaining is chosen from knowledge on filling intervals for optimized cooling. For information on the calculation of recovery, please see description in section 4.7.1.3.

**2.F.1.e Mobile AC**

There is currently no production of cars in Norway, and hence is there not calculated any emissions from initial emissions. The average lifetime on private cars and vans in Norway is approximately 18 and 15 years respectively. It is assumed that the average lifetime for all mobile air condition is lower than this. An annual leakage of 10% is chosen from the lower end of recommended range in IPCC 2006 guidelines and is also supported from the industry. An initial charge remaining of 60% is chosen from information regarding expected service interval on private cars and buses. Information from the car industry indicates a recovery rate in the higher end of the recommended range in the guidelines. According to the industry, scrapped vehicles are emptied for refrigerant gas as a part of the scrapping process. Some of the gas is delivered for destruction (see description in section 4.7.1.3) and some gas is cleaned and reused.

**2.F.1.f Stationary AC**

Equipment in stationary AC is either built and filled with fluorinated substances on site or installed as prefabricated and imported heat pumps. They will thus have emissions both in the production phase and from operation/use in the subsequent years. The IPCC 2006 Guidelines recommends an initial emission factor between 0.2 and 1% for this application category. In the 2021-submission it has been found grounds to differ this factor through the timeseries. It is expected higher initial emissions in the 90's and that these emissions are reduced from 1% to 0.2% from 2000 and onwards due to new improved installation techniques. The operational emission of 4% is within the IPCC range. For information on the calculation of recovery, please description in section 4.7.1.3.

**4.7.1.5 Uncertainties and time series consistency**

The uncertainties of the different components of the national greenhouse gas inventory have been evaluated in detail in 2006 by Statistics Norway (See annex II) and reviewed in 2022. The leakage rate and lifetime are considered quite uncertain and are estimated to be +50% for both HFC and PFC. The quality of activity data is considered quite good and are estimated to be 10% for both HFC and PFC.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

**4.7.1.6 Category-specific QA/QC and verification**

In addition to the general QA/QC procedures described in Annex V, the activity data, emissions figures, and the model used to estimate emissions are checked by several manual and automatic controls performed during and after the production of the figures.

Firstly, the activity data on imports and exports of chemicals undergo automatic checks before they are used as input for the emission calculations. Double counting and missing values are flagged and checked at a detailed level, i.e., for each observation of amount of chemical by importer/exporter and goods.

Aggregated figures for amount of chemical imported/exported for each year are then checked manually as they are entered into excel sheets containing time series for each CRF equipment/emission source. Potential errors like missing values or major differences in figures between years are checked and corrected if necessary. Aggregated figures on imports per gas are also compared with tables from the Norwegian Directorate of Customs and Excise, to check that our computerized coding has not altered the total amounts of import per gas. These controls would probably benefit from being automatic in the future.

Both activity data and emissions per chemical and type of equipment/emission source undergo controls in the excel sheets where the emissions calculations take place: Potential emissions are compared with actual emissions and IEFs are calculated and checked. Currently, these controls are only applied to the most important emission sources. The controls would probably also benefit from being automatic in the future.

The estimated emissions are finally subjected to several controls to identify errors in activity data and/or the calculation model. This includes the flagging of:

- Emissions from combinations of industrial sector and type of chemical that have not occurred previous years
- Emissions from combinations of industrial sector and type of chemical that occurred the previous year, are not occurring this year
- Large or small emissions compared with the previous years:
  - By type of chemical and sector
  - By type of chemical and CRF/NFR emission source
  - Recalculations

#### **4.7.1.7 Category-specific recalculations**

There has been a correction of error in 2019 and 2020. The error led to incorrect distribution of HFC-134a between the sectors. In addition, there has been a correction in the activity data in 2019. The overall result was a reduction of 284 and 1 454 tonnes CO<sub>2</sub> equivalents in 2019 and 2020, respectively.

Minor corrections have been made in subsector 2.F1.e Mobile Air condition due to a calculation error in the period 2010-2020.

Details are given in chapter 10.

#### **4.7.1.8 Category-specific planned improvements**

The quality improving work in 2020 revealed subjects that need further investigation. The recovery rate for domestic refrigeration, mobile AC, plug in refrigeration and transport refrigeration will be evaluated due to information about practice and the nature of the processes in end-of-life handling. This work will be done in cooperation with the industry and expert opinions. The work has started up, but no conclusions has been implemented.

### **4.7.2 Other applications, 2F6**

#### **4.7.2.1 Category description**

Due to confidentiality restrictions, Norwegian emissions from categories 2.F.2 (foam blowing), 2.F.3 (fire extinguishers), 2.F.4 (aerosols/metered dose inhalers (MDI)) and 2.F.5 (solvents) are reported in the CRF tables using the notation key "IE" and aggregated under 2.F.6 (Other applications using ODS substitutes) and not disaggregated by substance. Note however, that the calculations are made for each subsector.

In response to a recommendation from an earlier technical expert review team, more transparent information on the uses and the levels of emissions per capita compared to other Parties was included in the NIR. This information is shown below.

More than 95% of the Norwegian emissions reported in 2F6 since 1995, in terms of CO<sub>2</sub> equivalents<sup>15</sup>, were from:

Foam blowing agents (2.F.2), i.e., emissions of HFC-134a and HFC-152a from the use of hard foam/ closed cells-products. For HFC-134a the per capita emissions were in the range of 0 - 1.6 kg CO<sub>2</sub> equivalents before 1998, 2.3 - 4.4 kg CO<sub>2</sub> equivalents in the period 1998 to 2012 and 1.3 - 4.4 kg CO<sub>2</sub> equivalents in the period 2013 - 2021. Per capita emissions in comparable countries were in the range of 0 - 11.71 kg CO<sub>2</sub> equivalents in 2012. For HFC-152a the per capita emissions were in the range of 0 - 0.8 kg CO<sub>2</sub> equivalents in the period 1990 - 2012 and approximately 0.8 kg from 2012 - 2021. Per capita emissions in comparable countries were in the range of 0 - 1.74 kg CO<sub>2</sub> equivalents in 2012.

Aerosol (2.F.4), i.e., emissions from the use of HFC-134a in metered dose inhalers (2.F.4.a). The per capita emissions have grown from 0 - 3.0 kg CO<sub>2</sub> equivalents per capita before 2000, to 3.5 - 4.4 kg CO<sub>2</sub> equivalents per capita in the period 2001 - 2017. The amounts are

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<sup>15</sup> Note that the reported emissions in sector 2F6 are given in CO<sub>2</sub>-eq.

decreasing and rapidly reduced after 2018. Per capita emissions in comparable countries were in the range of 0.24 - 12.91 kg CO<sub>2</sub> equivalents in 2012.

Fire extinguishers (2.F.3), both in use and in the waste phase, of the gases HFC-125, HFC-134a and HFC-227ea). The emissions have increased from 0 - 0.3 kg CO<sub>2</sub> equivalents per capita before 2011, to a stable level in the range 2.1 - 3.0 kg CO<sub>2</sub> equivalents per capita in the period 2011 - 2021. Comparable countries had emissions in the range of 0.59 - 6.78 kg CO<sub>2</sub> equivalents per capita in 2012.

As can be seen from the list above, the Norwegian per capita emission for each of these three sectors in 2012 was well within the range of the selected comparable countries (Austria, Denmark, Finland, Ireland, Sweden, United Kingdom and United States). For the other categories included in the aggregated 2.F.6 amount, the emitted amounts were zero or close to zero. This explains the difference from the other comparable countries in the overall 2F2 to 2F6 amount. The increase in the reported Norwegian aggregated 2F6 emission since 2009 is due to 2F4 (metered dose inhalers, HFC-134a, from stocks).

A further comparison is done using data available through the UNFCCC website. [Table 4.49](#) below shows the per capita reported emissions in 2020 for 2F2-2F6 for same countries above and Norway is within the range of these countries.

| <b>Table 4.49 Per capita emissions for 2F2-2F6.</b>  |                                                              |
|------------------------------------------------------|--------------------------------------------------------------|
| Country                                              | Per capita emissions (tonnes CO <sub>2</sub> eq) for 2F2-2F6 |
| United States of America                             | 0.115                                                        |
| United Kingdom of Great Britain and Northern Ireland | 0.029                                                        |
| Ireland                                              | 0.024                                                        |
| Norway                                               | 0.008                                                        |
| Austria                                              | 0.073                                                        |
| Sweden                                               | 0.004                                                        |
| Finland                                              | 0.004                                                        |
| Denmark                                              | 0.002                                                        |

Source: UNFCCC, Norwegian Environment Agency

#### **4.7.2.2 Methodological issues**

See description for source category 2F1.



#### 4.7.2.3 Activity data

See description for source category 2F1.

#### 4.7.2.4 Emission factors

Leakage rates and product lifetimes used in the calculations are shown in Table 4.50.

| Table 4.50 Emission factors* for HFCs from products and lifetime of products |                  |                                                   |                                              |
|------------------------------------------------------------------------------|------------------|---------------------------------------------------|----------------------------------------------|
| Source category                                                              | Lifetime (years) | Production/initial emission (% of initial charge) | Lifetime emission (% of initial charge/year) |
| 2.F.2 Foam                                                                   |                  |                                                   |                                              |
| 2.F.2a Closed cells                                                          | 20               | 5                                                 | 4.5                                          |
| 2.F.2b Open cells                                                            | NO               | NO                                                | NO                                           |
| 2.F.3 Fire protection                                                        | 15               | 2                                                 | 5                                            |
| 2.F.4 Aerosols                                                               |                  |                                                   |                                              |
| 2.F.4.a Metered Dose Inhalers                                                | 2                | NO                                                | 50                                           |
| 2.F.4.b Other aerosols                                                       | 2                | NO                                                | 50                                           |
| 2.F.5 Solvents                                                               | 2                | NO                                                | 50                                           |

Source: \*IPCC (2006)

#### 4.7.2.5 Uncertainties and time series consistency

See description for source category 2F1.

#### 4.7.2.6 Category-specific QA/QC and verification

See description for source category 2F1.

#### 4.7.2.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

#### 4.7.2.8 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 4.8 Other product manufacture and use – 2G

Norway reports the source categories electric equipment, SF<sub>6</sub> and PFCs from other product use, medical applications, propellant for pressure and aerosol cans and other use of N<sub>2</sub>O under the category 2G, see Table 4.51.

**Table 4.51 Other product manufacture and use. Components included in the inventory, tier of method and key category.**

| Source category                                      | HFCs | PFCs | SF <sub>6</sub> | NF <sub>3</sub> | N <sub>2</sub> O | Tier   | Key category |
|------------------------------------------------------|------|------|-----------------|-----------------|------------------|--------|--------------|
| 2G1.Electric equipment                               | NO   | NO   | E               | NO              | NA               | Tier 2 | No           |
| 2G2. SF <sub>6</sub> and PFCs from other product use | NA   | NO   | E               | NO              | NA               | Tier 1 | No           |
| 2G3a. Use of <b>N<sub>2</sub>O</b> in anaesthesia    | NA   | NA   | NA              | NA              | E                | Tier 1 | No           |
| 2G3b.1. Propellant for pressure and aerosol cans     | NA   | NA   | NA              | NA              | E                | Tier 1 | No           |
| 2G3b.2. Other use of <b>N<sub>2</sub>O</b>           | NA   | NA   | NA              | NA              | E                | Tier 1 | No           |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occuring. IE = Included Elsewhere*

Table 4.52 shows the emission trends for 2G as a whole and for the various sub-categories. The GHG emissions from this sector category were about 75 kt in 2021, this is 0.8% of the total emission from the IPPU-sector. The emissions from this sector have decreased by 12.2% from 1990 and the emissions decreased by 14.3% from 2020 to 2021.

| <b>Table 4.52 Emission trends for 2G Other product manufacture and use (t CO<sub>2</sub> equivalents).</b> |        |                 |        |        |                 |                     |                     |
|------------------------------------------------------------------------------------------------------------|--------|-----------------|--------|--------|-----------------|---------------------|---------------------|
| Source category                                                                                            | 1990   | 1990, % of IPPU | 2020   | 2021   | 2021, % of IPPU | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
| 2G1.Electric equipment                                                                                     | 52 715 | 0.4             | 47 284 | 34 020 | 0.4             | -35.5               | -28.1               |
| 2G2c. Soundproof windows                                                                                   | 2 301  | 0.0             | 23 764 | 23 527 | 0.3             | 922.5               | -1.0                |
| 2G2e. Other                                                                                                | 0      | 0.0             | 3 760  | 3 760  | 0.0             | NA                  | 0.0                 |
| 2G3a. Medical applications                                                                                 | 30 375 | 0.2             | 10 915 | 11 862 | 0.1             | -60.9               | 8.7                 |
| 2G3b1. Propellant for pressure and aerosol products                                                        | -      | 0.0             | 1 405  | 1 405  | 0.0             | NA                  | 0.0                 |
| 2G3b2, Other                                                                                               | -      | 0.0             | 362    | 362    | 0.0             | NA                  | 0.0                 |
| 2G. Total                                                                                                  | 85 391 | 0.6             | 87 489 | 74 935 | 0.8             | -12.2               | -14.3               |

Source: Statistics Norway and Norwegian Environment Agency

As part of the transformation to new reporting guidelines, Norway has examined whether there are activities that would result in emissions of trinitrogenfluoride (NF<sub>3</sub>). Our assessment is that there are no emissions of NF<sub>3</sub> in Norway.

## 4.8.1 Electric equipment, 2G1

### 4.8.1.1 Category description

SF<sub>6</sub> is used as an insulation medium in high tension electrical equipment including gas insulated switchgear (GIS) and circuit breakers. There is no production of SF<sub>6</sub> in Norway. In March 2002 a voluntary agreement was signed between the Ministry of Environment and the most important users and producers of GIS. According to this agreement emission from this sector should be reduced by 13% in 2005 and 30% in 2010 with 2000 as base year. For the following up of this agreement, the users (electricity plants and –distributors) and producer (one factory) report annually to the government. This voluntary agreement terminated successfully in 2010, but a continuation is being discussed. Although the voluntary agreement has terminated, the users still report annually to the Norwegian Environmental Agency.

#### 4.8.1.2 Methodological issues

The general methodology for estimating SF<sub>6</sub> emissions was revised in a SFT report (SFT 1999c), while the sector specific methodology for GIS, AIS and medium voltage switchgear were revised in the 2022 reporting based on new information from the Norwegian users.

Emissions from production of GIS (one factory) were included for the first time in 2003. The company has, as part of the voluntary agreement with the Ministry of the Environment, made detailed emission estimates back to 1985. These emissions constitute a significant part of national emissions of SF<sub>6</sub>. In recent years emissions rates have been considerably reduced due to new investments and better routines. The company now performs detailed emission calculations based on accounting of the SF<sub>6</sub> use throughout the whole production chain. Due to confidentiality, emissions from production are reported under emissions from stock.

In the period of 1990-2002 the estimates of emissions of SF<sub>6</sub> have been made upon the information in SFT report (SFT 1999c). The emissions are calculated with emission factors from Table 4.53.

From 2003 and onwards the reporting group of users of SF<sub>6</sub> in electrical equipment have reported detailed figures on the amounts in stock, reuse, destructured, refilling and new equipment. The group of users cover a high share of the total users. An evaluation of the shares in 2020 led to a share as given in Table 4.53.

**Table 4.53 Share of users of SF<sub>6</sub> reporting annually to the Norwegian Environmental Agency.**

|                                  | Share of users reporting |
|----------------------------------|--------------------------|
| GIS ≥ 60kV                       | 95%                      |
| AIS ≥ 60kV                       | 80%                      |
| medium voltage switchgear < 60kV | 60%                      |

An important assumption in the calculations is that the reported figures reflect the activity in the rest of the population. This information makes a solid basis for calculation of annual country specific emission factors.

The calculation follows the tier 2 method as given in the IPCC (2006).

#### 4.8.1.3 Activity data

Data is collected from companies that use SF<sub>6</sub> in various equipment and processes. The calculations take into account imports, exports, recycling, accumulation in bank, technical

lifetimes of products, and different rates of leakage from processes, products and production processes. From 2003 and onwards emission estimates reported directly from users and producers, according to the voluntary agreement, are important input.

#### 4.8.1.4 Emission factors

The product lifetime is assumed to be 50 years in the whole period for all emission sources. Leakage rates used in the calculations in are shown in Table 4.54.

| Table 4.54 Leakage rates from products containing SF <sub>6</sub> , per cent. |                                  |         |
|-------------------------------------------------------------------------------|----------------------------------|---------|
| Product emission source                                                       | Sealed medium voltage switchgear | GIS/AIS |
| 1990-2000                                                                     | 0.2                              | 1.0     |
| 2005                                                                          | 0.2                              | 0.44    |
| 2010                                                                          | 0.27                             | 0.4     |
| 2012                                                                          | 0.27                             | 0.35    |
| 2013                                                                          | 0.27                             | 0.37    |
| 2014                                                                          | 0.27                             | 0.34    |
| 2015                                                                          | 0.31                             | 0.3     |
| 2016                                                                          | 0.31                             | 0.24    |
| 2017                                                                          | 0.31                             | 0.2     |
| 2018                                                                          | 0.31                             | 0.22    |
| 2019                                                                          | 0.31                             | 0.22    |
| 2020                                                                          | 0.35                             | 0.3     |
| 2021                                                                          | 0.35                             | 0.2     |

Source: SFT (1999c), Statistics Norway

#### 4.8.1.5 Uncertainties and time series consistency

An uncertainty estimate is given in Annex II. The uncertainty has been revised in the 2022 reporting. The uncertainty of 10 per cent for the activity data and 60 per cent for the emission factors is an updated expert judgement (Rypdal & Zhang 2000).

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### 4.8.1.6 Category-specific QA/QC and verification

The current methodology was first established in the SFT report (SFT 1999c), with emissions from GIS calculated from stock data estimates and leakage factors. It was revised in 2004 when data from the voluntary agreement on GIS became available, with emissions estimated from reported data on refilling (Hansen 2007). The methodology was

revised again in the 2022 reporting and confirmed the assumptions in previous reviews in early time series.

#### **4.8.1.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.8.1.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.8.2 SF<sub>6</sub> and PFC from other product use, 2G2**

#### **4.8.2.1 Category description**

This source category includes SF<sub>6</sub> emissions from other product use.

#### **4.8.2.2 Methodological issues**

The method for other sources is described in a SFT report (SFT 1999c). For tracer gas, medical use, and other minor uses, the activity data are annual consumption as estimated in the SFT report. However, for tracer gas some major research projects expired in 2001 and 2006, respectively, and the consumption has been reduced. For sound-insulating windows and footwear, the emissions are calculated from estimated stock of SF<sub>6</sub> in the products, and from production of windows. Footwear with SF<sub>6</sub> was imported, and the use ended in 2001. There was no production of sound-insulating windows from 2008.

These sound-insulating windows were used from 1985 and have a lifetime of 30 years. The increase in emissions from 2014 to 2015 is due to the phasing out of the first windows and the remaining SF<sub>6</sub> in those windows is reported as emitted.

#### **4.8.2.3 Activity data**

Data is collected from direct consultations with importers and exporters of bulk chemicals and products containing SF<sub>6</sub>. The activity data are annual additions of SF<sub>6</sub> to the product stock, as estimated by SFT (1999c). The calculations take into account imports, exports, recycling, accumulation in bank, technical lifetimes of products, and different rates of leakage from processes, products and production processes.

In addition to the activity data described above, the calculations include emissions from uncontrolled accidents. There was one incident in 2017 leading to an unusual peak in emissions from stocks in 2G2e, about 1.3 times as large as the surrounding years.

#### 4.8.2.4 Emission factors

Leakage rates and product lifetimes used in the calculations are shown in Table 4.545 and Table 4.556.

| Table 4.55 Yearly rate of leakage of SF <sub>6</sub> from different processes. |                                               |
|--------------------------------------------------------------------------------|-----------------------------------------------|
| Emission source                                                                | Leakage rate (% of input of SF <sub>6</sub> ) |
| Secondary magnesium foundries                                                  | 100                                           |
| Tracer gas in the offshore sector                                              | 0                                             |
| Tracer gas in scientific experiments                                           | 100                                           |
| Medical use (retinal surgery)                                                  | 100                                           |
| Production of sound-insulating windows                                         | 2 *                                           |
| Other minor sources                                                            | 100                                           |

Source: SFT (1999c)

\* 1% after 2002

| Table 4.56 Product lifetimes and leakage rates from products containing SF <sub>6</sub> . |                        |                          |
|-------------------------------------------------------------------------------------------|------------------------|--------------------------|
| Product emission source                                                                   | Yearly rate of leakage | Product lifetime (years) |
| Sound-insulating windows                                                                  | 1                      | 30                       |
| Footwear (trainers)                                                                       | 25                     | 9                        |
| Other minor sources                                                                       |                        |                          |

Source: SFT (1999c)

#### 4.8.2.5 Uncertainties and time series consistency

An uncertainty estimate is given in Annex II. The uncertainty of 60% is an expert judgement (Rypdal & Zhang 2000).

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### 4.8.2.6 Category-specific QA/QC and verification

The current methodology was established in a SFT report (SFT 1999c), with emissions from GIS calculated from stock data estimates and leakage factors. It was revised in 2004 when data from the voluntary agreement on GIS became available, with emissions estimated from reported data on refilling (Hansen 2007).

#### 4.8.2.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

#### **4.8.2.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.8.3 Use of N<sub>2</sub>O in anaesthesia, 2G3a**

#### **4.8.3.1 Category description**

N<sub>2</sub>O is used in anaesthesia procedures in hospitals, by dentists and by veterinarians.

#### **4.8.3.2 Methodological issues**

N<sub>2</sub>O is used in anaesthesia procedures and will lead to emissions of N<sub>2</sub>O. For the year 1998 and annually from 2000, the emissions are given by data on sales of N<sub>2</sub>O for medical uses from the three major producers and importers in Norway. The data include N<sub>2</sub>O used as anaesthesia in hospitals, by dentist and by veterinarians. For the year 1999, sales figures have been interpolated between 1990 and 2000. For the years prior to 1998, annual consumption is estimated on basis of sales figures for 1998 and the number of births and number of bed nights in hospitals for each year to estimate consumption. For the years 1990-1998, no N<sub>2</sub>O is assumed used by dentists and veterinarians as the amounts they used in 2000 were very small.

#### **4.8.3.3 Activity data**

For this source actual sale of N<sub>2</sub>O is used for the year 1998, and annually from 2000. For the calculations of use prior to 1998, annual number of births and bed nights in hospitals are taken from the Statistical yearbook of Norway.

#### **4.8.3.4 Emission factors**

The figures are based on sales of N<sub>2</sub>O.

#### **4.8.3.5 Uncertainties and time-series consistency**

The figures are uncertain. There may be small importers not included in Statistics Norway's telephone survey with 2000 and the investigation done by the Norwegian Environment Agency in 2014, but the emissions are small, so it is believed that the uncertainty is at an acceptable level.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.8.3.6 Category-specific QA/QC and verification**

There is no source specific QA/QC procedure for this sector. See Annex V for the description of the general QA/QC procedure.



#### **4.8.3.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.8.3.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.8.4 Propellant for pressure and aerosol products, 2G3b.1.**

#### **4.8.4.1 Category description**

N<sub>2</sub>O is used as a propellant in spray boxes and this use will lead to emissions of N<sub>2</sub>O. It is also used in research work, for instance in the food industry and at universities. There is no production of N<sub>2</sub>O for these purposes in Norway.

#### **4.8.4.2 Methodological issues**

Information on sale volumes has been reported by the plants to Statistics Norway. It is assumed that all propellant is released to air.

#### **4.8.4.3 Activity data**

Information has been gathered from the plants indicating that there is no production or sale of N<sub>2</sub>O for use as a propellant in Norway. The N<sub>2</sub>O is already in the spray cans when imported. There was no import of these spray cans prior to 1993. For the years 1994-2002 the number of cans imported in 1994 have been used as activity data, while the number of cans imported in 2003 has been used as activity data for all years since.

#### **4.8.4.4 Emission factors**

Not relevant.

#### **4.8.4.5 Uncertainty and time-series consistency**

The figures for one year are used for all years. It is believed that all figures from all major importers are included in the inventory.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.8.4.6 Category-specific QA/QC and verification**

There is no source specific QA/QC procedure for this sector. See Annex V for the description of the general QA/QC procedure.

#### **4.8.4.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.8.4.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

#### **4.8.5 Other use of N<sub>2</sub>O, 2G3b.2**

##### **4.8.5.1 Category description**

Small amounts of N<sub>2</sub>O are used for research work and for drag-racing.

There were no emissions of N<sub>2</sub>O from use in research and for drag racing in 1990. The use has been estimated to 407 tonnes CO<sub>2</sub> equivalents from the year 1993 and onwards.

##### **4.8.5.2 Methodological issues**

Data on imported amounts in 2002 has been used for all years and it is assumed that all propellant is released to air.

##### **4.8.5.3 Activity data**

Data on imported amounts in 2002 has been used for all years.

##### **4.8.5.4 Emission factors**

Not relevant.

##### **4.8.5.5 Uncertainty and time-series consistency**

The figures for one year are used for all years. A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

##### **4.8.5.6 Category-specific QA/QC and verification**

There is no source specific QA/QC procedure for this sector. See Annex V for the description of the general QA/QC procedure.

##### **4.8.5.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

##### **4.8.5.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 4.9 Other – 2H

Under Other production, Norway reports the two source categories pulp and paper and food and beverages industry, see [Table 4.57](#).

**Table 4.57 Other production. Components included in the inventory, tier of method and key category.**

| Source category                  | CO <sub>2</sub> | NMVOC | Tier   | Key category |
|----------------------------------|-----------------|-------|--------|--------------|
| 2H1. Pulp and paper              | R               | NA    | Tier 2 | No           |
| 2H2. Food and beverages industry | R               | E     | Tier 2 | Yes          |

*R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated. NA = Not Applicable. NO = Not Occurring. IE = Included Elsewhere.*

Table 4.58 shows the emission trends for 2H as a whole and for the various sub-categories. The GHG emissions from this sector category were 113 kt in 2021, this is 1.3% of the total emission from the IPPU-sector. The emissions from this sector increased by 260.4% from 1990 and the emissions decreased by 5.8% from 2020 to 2021.

**Table 4.58 Emission trends for 2H Other (t CO<sub>2</sub> equivalents).**

| Source category                  | 1990   | 1990, % of IPPU | 2020    | 2021    | 2021, % of IPPU | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
|----------------------------------|--------|-----------------|---------|---------|-----------------|---------------------|---------------------|
| 2H1. Pulp and paper              | 10 485 | 0.1             | 9 283   | 9 163   | 0.1             | -12.6               | -1.3                |
| 2H2. Food and beverages industry | 20 787 | 0.1             | 110 297 | 103 527 | 1.1             | 398.0               | -6.1                |
| 2H. Total                        | 31 272 | 0.2             | 119 580 | 112 690 | 1.3             | 260.4               | -5.8                |

*Source: Statistics Norway and Norwegian Environment Agency*

### 4.9.1 Pulp and paper, 2H1

#### 4.9.1.1 Category description

There are CO<sub>2</sub> emissions from non-combustion from two plants in this sector and they are covered by the EU ETS. The emissions originate from the use of limestone. Emissions from combustion are included in Chapter 3.

#### 4.9.1.2 Methodological issues

The CO<sub>2</sub> emissions are calculated by multiplying the amount of limestone by an emission factor.

#### **4.9.1.3 Activity data**

Activity data is reported by the plants to the agency. The amount of limestone is calculated from purchased amount, adjusted for the amount of limestone in storage in the beginning and end of the year. The aggregate amounts of limestone used by the plants included in 2H1 are reported in the CRF Table 2(l). A-Hs2 and are shown in [Table 4.5](#) for some selected years in the time series.

#### **4.9.1.4 Emission factors**

The emission factor used in the calculation is 0.44 tonne CO<sub>2</sub> per tonne limestone.

#### **4.9.1.5 Uncertainties and time-series consistency**

Uncertainty estimates are given in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.9.1.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII. The plants are covered by the EU ETS and their emissions are verified annually. In addition, the emissions are checked both by the case handler and by the agency's inventory team.

#### **4.9.1.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.9.1.8 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### **4.9.2 Food and beverages industry, 2H2 (key category for CO<sub>2</sub>)**

#### **4.9.2.1 Category description**

This source category includes CO<sub>2</sub> from carbonic acid mainly used in breweries, domestic use of captured CO<sub>2</sub>, imported CO<sub>2</sub> and CO<sub>2</sub> from production of bio protein.

Some CO<sub>2</sub> from the production of ammonia (2B1) is captured and in Norway mainly used as carbonic acid in carbonated beverages. The emissions reported here in 2H2 include CO<sub>2</sub> bound in products and imported CO<sub>2</sub>. The emissions are reported in this source category, although the largest part of the emissions takes place after the bottles is opened and not in the breweries. Exported CO<sub>2</sub> from this source is not included in the Norwegian emission inventory.

One plant produced bio protein in the years 2001-2005. Natural gas was used to feed the bacteria cultures that produced the bio protein, and this was used as animal fodder. CO<sub>2</sub> emissions from food and beverages industry is defined as a key category according to the approach 1 analysis.

#### 4.9.2.2 Methodological issues

For carbonic acid, the CO<sub>2</sub> figures are based on the sales and export statistics from the ammonia producing plant and import statistics from Statistics Norway's External trade in goods statistics.

For the production of bio protein, the plant reported emissions of about 2 000 – 11 000 tonnes CO<sub>2</sub> and these are included in the national inventory.

#### 4.9.2.3 Activity data

For carbonic acid, the CO<sub>2</sub> figures are based on the sales and export statistics from the ammonia producing plant and import statistics from Statistics Norway's External trade in goods statistics, see [Table 4.59](#).

| <b>Table 4.59 Sold CO<sub>2</sub> (minus exports), imported CO<sub>2</sub> and domestic use (ktonnes).</b> |                                      |                          |                                       |
|------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------|---------------------------------------|
| Year                                                                                                       | Sold CO <sub>2</sub> (minus exports) | Imported CO <sub>2</sub> | Domestic use of CO <sub>2</sub> (2H2) |
| 1990                                                                                                       | 20.0                                 | 0.8                      | 20.8                                  |
| 1995                                                                                                       | 34.0                                 | 2.4                      | 36.4                                  |
| 2000                                                                                                       | 50.0                                 | 2.6                      | 52.6                                  |
| 2005                                                                                                       | 53.0                                 | 18.4                     | 71.4                                  |
| 2010                                                                                                       | 76.0                                 | 8.7                      | 84.7                                  |
| 2012                                                                                                       | 81.4                                 | 13.6                     | 95.0                                  |
| 2013                                                                                                       | 78.0                                 | 13.2                     | 91.3                                  |
| 2014                                                                                                       | 83.7                                 | 7.7                      | 91.4                                  |
| 2015                                                                                                       | 88.6                                 | 11.1                     | 99.8                                  |
| 2016                                                                                                       | 80.4                                 | 24.9                     | 105.4                                 |
| 2017                                                                                                       | 45.8                                 | 59.8                     | 105.6                                 |
| 2018                                                                                                       | 91.3                                 | 21.6                     | 112.9                                 |
| 2019                                                                                                       | 83.5                                 | 21.8                     | 105.4                                 |
| 2020                                                                                                       | 79.7                                 | 30.6                     | 110.3                                 |
| 2021                                                                                                       | 71.3                                 | 32.2                     | 103.5                                 |

Sources: Statistics Norway and the Norwegian Environment Agency

For the production of bio protein, the activity data is the amount of natural gas used in the process.

#### **4.9.2.4 Emission factors**

The activity data for carbonic acid is CO<sub>2</sub>, so emission factors are not relevant.

#### **4.9.2.5 Uncertainties and time-series consistency**

See the uncertainty in the activity data for the ammonia plant (2B1) in Annex II.

A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

#### **4.9.2.6 Category-specific QA/QC and verification**

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for Industrial processes is described in Annex VII.

#### **4.9.2.7 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

#### **4.9.3 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 5. Agriculture (CRF sector 3)

### 5.1 Overview of sector

About 9.6% of the total Norwegian emissions of greenhouse gases (GHG) originated from agriculture in 2021. This corresponds to 4.7 million tonnes CO<sub>2</sub> eq. Emissions from agriculture were in 2021 about 5% lower than in 1990, and about 1% higher than in 2020.

The sector's clearly biggest sources of GHG's were enteric fermentation (CH<sub>4</sub>) from domestic animals contributing with 54% of the sector's emissions, and N<sub>2</sub>O from agricultural soils contributing with 31%. Manure management contributed with about 12%. CO<sub>2</sub> emissions in the agriculture sector, mainly from liming and a minor part from urea application, contributed with 3%. There are also some minor emissions of the greenhouse gases N<sub>2</sub>O and CH<sub>4</sub> arising from the burning of crop residues on the fields.

**Table 5.1 Emissions from Agriculture categories in 1990, 2020 and 2021 (ktonnes CO<sub>2</sub> equivalents).**

| Category                                  | 1990  | 1990, % of Agriculture | 2020  | 2021  | 2021, % of Agriculture | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
|-------------------------------------------|-------|------------------------|-------|-------|------------------------|---------------------|---------------------|
| 3A Enteric fermentation                   | 2 704 | 55 %                   | 2 521 | 2 557 | 54 %                   | -5 %                | 1 %                 |
| 3B Manure management                      | 511   | 10 %                   | 543   | 551   | 12 %                   | 8 %                 | 1 %                 |
| 3D Agricultural soils                     | 1 462 | 30 %                   | 1 453 | 1 468 | 31 %                   | 0 %                 | 1 %                 |
| 3F Field burning of agricultural residues | 38    | 1 %                    | 4     | 4     | 0 %                    | -90 %               | -14 %               |
| 3G Liming                                 | 231   | 5 %                    | 127   | 122   | 3 %                    | -47 %               | -5 %                |
| 3H Urea application                       | 1     | 0 %                    | 0     | 0     | 0 %                    | -83 %               | 17 %                |
| Total                                     | 4 947 | 100 %                  | 4 649 | 4 702 | 100 %                  | -5 %                | 1 %                 |

Source: Statistics Norway and the Norwegian Environment Agency

Agriculture contributes particularly to CH<sub>4</sub>, N<sub>2</sub>O and NH<sub>3</sub> emissions. Domestic animals are the major source of CH<sub>4</sub> emissions from agriculture. Both enteric fermentation and manure management contribute to emissions of CH<sub>4</sub>. Manure management also generates emissions of N<sub>2</sub>O.

Microbiological processes in soil lead to emissions of N<sub>2</sub>O. Both direct and indirect N<sub>2</sub>O from soil processes are described in the IPCC methodology and are included in the Norwegian inventory. Direct N<sub>2</sub>O emissions arising from the use of fertilizer (manure, synthetic fertilizer, sewage sludge and other organic fertilizers applied to soils), emissions from pastures, crop residues and cultivation of organic soils are included. Indirect N<sub>2</sub>O emissions from atmospheric deposition and nitrogen leaching and run-off from both the manure management systems and from agricultural soils are also included.

Manure storage and the use of fertilizer (manure, synthetic fertilizer, sewage sludge and other organic fertilizers applied to soils) also generate emissions of ammonia (NH<sub>3</sub>) and NO<sub>x</sub> that gives indirect N<sub>2</sub>O from atmospheric deposition. NH<sub>3</sub> volatilized from grazing animals are also included in the estimations of indirect N<sub>2</sub>O.

As indicated in chapter 1.5, the Approach 2 key category analysis performed in 2023 for the years 1990 and 2021 has revealed key categories in terms of total level and/or trend uncertainty in the agriculture sector as shown in [Table 5.2](#). The key categories according to Approach 1 key category analysis are also provided in [Table 5.2](#).

| <b>Table 5.2 Key categories in the sector Agriculture.</b> |                                                                                   |                  |                                    |        |
|------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------|------------------------------------|--------|
| IPCC                                                       | Source category                                                                   | Gas              | Key category according to approach | Method |
| 3A1                                                        | Enteric fermentation - Cattle                                                     | CH <sub>4</sub>  | 2                                  | Tier 2 |
| 3A2                                                        | Enteric fermentation - Sheep                                                      | CH <sub>4</sub>  | 2                                  | Tier 2 |
| 3B1                                                        | Manure management - Cattle                                                        | CH <sub>4</sub>  | 2                                  | Tier 2 |
| 3B                                                         | Manure management                                                                 | N <sub>2</sub> O | 2                                  | Tier 2 |
| 3Da1                                                       | Direct emissions from managed soils - Inorganic N fertilizers                     | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3Da2                                                       | Direct emissions from managed soils - Organic N fertilizers                       | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3Da3                                                       | Direct emissions from managed soils – Urine and dung deposited by grazing animals | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3Da4                                                       | Direct emissions from managed soils - Crop residues                               | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3Da6                                                       | Direct emissions from managed soils - Cultivation of organic soils                | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3Db1                                                       | Indirect emissions from managed soils – Atmospheric deposition                    | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3Db2                                                       | Indirect emissions from managed soils – Nitrogen leaching and run-off             | N <sub>2</sub> O | 2                                  | Tier 1 |
| 3G                                                         | Liming                                                                            | CO <sub>2</sub>  | 1                                  | Tier 1 |



## 5.1.1 Livestock population characterisation

### 5.1.1.1 Data sources

The animal population data used in the estimations on a disaggregated level are provided in Annex VIII, table AVIII-1 and AVIII-2. The same data for number of animals of the various animal groups is used in all the different calculations of emissions.

The main sources of the livestock statistics are the register of production subsidies (sheep for breeding, goats, breeding pigs, poultry for egg production and beef cows), statistics of approved carcasses (animals for slaughter) and the Cow Recording System at TINE BA<sup>16</sup> (TINE BA Annually) (heifers for breeding and dairy cows). These sources cover 80-100% of the animal populations. The estimated shortage of coverage is compensated in the total number of animals used in the emission estimates. The coverage in the data sources is shown in [Table 5.3](#).

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<sup>16</sup> TINE BA is the sales and marketing organisation for Norway's dairy cooperative and covers most of the milk production and the meat production induced by milk production.

| Table 5.3 Estimated coverage of animal populations in the data sources used. |                                         |                                                                  |                   |                  |
|------------------------------------------------------------------------------|-----------------------------------------|------------------------------------------------------------------|-------------------|------------------|
|                                                                              | Statistics Norway, production subsidies | Statistics Norway, statistics of approved carcasses <sup>4</sup> | TINE              | Other            |
| Dairy cows                                                                   |                                         | 100 <sup>2</sup>                                                 | 98.0 <sup>1</sup> |                  |
| Replacement heifers                                                          |                                         |                                                                  | 98.0 <sup>1</sup> |                  |
| Young cattle for slaughter                                                   |                                         | 100                                                              | 100 <sup>3</sup>  |                  |
| Beef cows                                                                    | 99.8                                    | 100 <sup>2</sup>                                                 |                   |                  |
| Sheep                                                                        | 99.6                                    | 100                                                              |                   |                  |
| Goats                                                                        | 100                                     |                                                                  |                   |                  |
| Laying hens                                                                  | 100                                     |                                                                  |                   |                  |
| Chicks for breeding                                                          | 100                                     |                                                                  |                   |                  |
| Chicken for slaughter                                                        |                                         | 100                                                              |                   |                  |
| Other poultry for breeding                                                   | 100                                     |                                                                  |                   |                  |
| Other poultry for slaughter                                                  |                                         | 100                                                              |                   |                  |
| Sows                                                                         | 98.7                                    |                                                                  |                   |                  |
| Young pigs for breeding                                                      | 100                                     |                                                                  |                   |                  |
| Pigs for slaughter                                                           |                                         | 100                                                              |                   |                  |
| Horses                                                                       | 100                                     |                                                                  |                   | 85 <sup>5</sup>  |
| Fur-bearing animals                                                          | 100                                     |                                                                  |                   |                  |
| Deer                                                                         | 100                                     |                                                                  |                   |                  |
| Reindeer                                                                     |                                         |                                                                  |                   | 100 <sup>6</sup> |

Source: Estimations by Statistics Norway and the Cow Recording System (dairy cows and heifers).

<sup>1</sup> Share of livestock herds.

<sup>2</sup> Data source only for slaughter weight

<sup>3</sup> Data source only for slaughter age

<sup>4</sup> Figure refers to share of slaughtered animals, excluding home slaughter. Animals dead from other causes also excluded

<sup>5</sup> Total number of horses used in the inventory is based on data from productions subsidies (54% of total number) and an additional estimation of number of horses outside agriculture by Nasjonalt hesteregister. As a total the coverage will be 91.9%.

<sup>6</sup> Norwegian Agriculture Agency

The statistics of approved carcasses covers close to 100% of all slaughtered animals. Home slaughter is not included, but the extent of home slaughter is very low due to legal restrictions. Even animals consumed by producers are in most cases registered at the slaughterhouses.

The number of dairy cows and heifers for breeding derive from the Cow Recording Systems (TINE BA Annually). Between 96 and 99% of all dairy cows are registered here, and in

addition, the number used in the inventory is adjusted for this missing part. The adjustment is based on the percentage of herds controlled by the cow recording system. The registers are updated annually. In addition to the animals included in these registers, an estimate of the number of other horses is obtained from the Norwegian Institute of Bioeconomy Research (NIBIO). The number of reindeer is obtained from the Norwegian Reindeer Husbandry Administration.

For the categories of animals living shorter than a full year or two, generally animals for slaughter, lifetime is taken into account to get a yearly average for the number of animals.

#### **5.1.1.2 Method for estimating number of cattle**

For dairy cows, additional information from the Cow Recording System concerning annual milk production and proportion of concentrate in the diet is used (TINE BA Annually). The Cow Recording System also supplies annual information about slaughter age for heifers and bulls and data for estimating live weight of dairy cows and heifers for breeding, and also the age of young cows at their first calving. (Moen, *pers. comm.*<sup>17</sup>).

For heifers and bulls for slaughter, animal numbers are based on data from statistics of approved carcasses which provide data on numbers slaughtered and slaughter weights. Combined with slaughter age from the Cow Recording System (TINE BA Annually), this gives a precise estimation of animal life time for each animal slaughtered. There are several reasons for this way of counting the animals:

- The coefficients for N and VS excretion (3B) and formation of methane (3A) are based on the development of the animals through their lifetime (weight gain, age, feed consumption). The information on these parameters is most precise when they are connected to the animals in this way.
- When using the number of animals slaughtered, there is an almost perfect coherence between the definition of the categories counted and the representation of the coefficients.
- Counting the number of animals slaughtered gives a very precise value of the number of animals.
- Counting the number of animals as number of live animals at specific dates (which is the only other alternative) takes away the possibility to group the animals in the five categories of young cattle that is being used in the definitions now because this statistic only gives the number of young cattle as a total.

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<sup>17</sup> Moen, O. (*annually*): Personal information, email from Oddvar Moen, Tine Rådgivning annually.

One principal draw-back of this method for estimating animal population is that emissions in all stages of these animals' lives will be accounted for in the year of slaughter, even though the emissions in the early stages of the lives of these animals to a large extent took place in the previous year. In a stable population of animals, this error is automatically adjusted for. Since animal populations are relatively stable, this error is considered much smaller compared to errors related to estimating animal year based on animal populations in the register of production subsidies which was previously used. The data sources used also ensure a better coherence between animal numbers, lifetime and weight. Estimated animal years for cattle are provided in [Table 5.4](#).

The number of milk cows calving for the first time (=heifers for replacement) and their average age at time of calving is reported by the Cow Recording System (TINE BA Annually) on request from Statistics Norway. These data date back to 2004. For the years 1990-2003, average fraction (number of heifers)/ (number of milk cows) for the years 2004-2011 is used to estimate number of heifers based on number of milk cows. Number of heifers for replacement in beef production is collected from annual reports from Animalia (Norwegian Meat and Poultry Research Centre ([www.animalia.no](http://www.animalia.no))). Figures exist from 2007. For previous years, the number is estimated with the same method as for heifers for milk production.

**Table 5.4 Estimated animal years for cattle.**

|      | Heifer for replacement | Heifers for slaughter | Bulls for slaughter | Beef cows <sup>1</sup> | Dairy cows |
|------|------------------------|-----------------------|---------------------|------------------------|------------|
| 1990 | 311 279                | 47 020                | 289 945             | 8 193                  | 325 896    |
| 1995 | 299 284                | 47 103                | 284 237             | 20 334                 | 310 346    |
| 2000 | 280 121                | 63 512                | 285 349             | 42 324                 | 284 880    |
| 2005 | 255 862                | 57 619                | 263 170             | 54 841                 | 255 663    |
| 2010 | 239 839                | 53 410                | 230 872             | 67 110                 | 232 294    |
| 2011 | 239 007                | 48 778                | 223 536             | 68 539                 | 224 721    |
| 2012 | 235 891                | 42 863                | 217 050             | 71 834                 | 229 767    |
| 2013 | 239 386                | 47 294                | 220 401             | 70 969                 | 225 163    |
| 2014 | 246 165                | 67 624                | 208 979             | 73 894                 | 222 553    |
| 2015 | 240 419                | 64 814                | 206 328             | 77 408                 | 222 553    |
| 2016 | 243 942                | 64 361                | 217 885             | 84 372                 | 220 461    |
| 2017 | 247 715                | 43 501                | 250 630             | 88 332                 | 215 849    |
| 2018 | 245 636                | 52 356                | 260 129             | 92 304                 | 211 730    |
| 2019 | 240 049                | 47 230                | 238 845             | 94 001                 | 199 417    |
| 2020 | 245 069                | 52 767                | 229 068             | 99 748                 | 195 076    |
| 2021 | 247 748                | 56 773                | 229 199             | 106 082                | 196 934    |

Source: Cow Recording System (TINE BA Annually)(dairy cows), slaughter statistics and estimations by Statistics Norway

### 5.1.1.3 Method for estimating number of sheep

In the estimations of emissions from manure management, the sheep population is divided between sheep > one year, and sheep < one year. Data from both the register of production subsidies and slaughter statistics is used in estimating the number of animals. In 2017 two changes appeared in the register data: The counting date changed from 1st of January to 1st of March, and the two categories' sheep > one year and sheep < one year were merged into one category for adult sheep. To solve this, figures are split into the two categories sheep > and < one year based on data from the Norwegian Meat and Poultry Center, Animalia. Sheep more than one year old is estimated as the number of sheep registered 1. of March deducted for the number of sheep slaughtered before May the same year. The sheep slaughtered later in the year are counted as living the whole year. Sheep less than one year old is estimated as number of sheep under one year registered 1st of March + number of lambs slaughtered June-December \*143/365. Lambs slaughtered before June are assumed to be registered as sheep under one year 1st of March. Practically all lambs slaughtered after June are born in the spring. An expert judgment suggests an average lifetime of 143 days for slaughtered lambs born in the spring (UMB, *pers. comm*<sup>18</sup>). In the estimations of enteric methane, sheep is split in four categories: sheep > 1 year, sheep < 1 year for breeding, lambs slaughtered June-Dec. and lambs slaughtered Jan.-May. Sheep over one year is estimated as explained above. Sheep under one year for breeding is estimated as the number of sheep under one year registered 1st of March deducted for the number of lambs slaughtered March-May. For the numbers of slaughtered lambs, slaughter statistics are used. The numbers of slaughtered lambs were previously estimated. A more detailed description of the method can be found in NIR 2020, Annex IX, section 1.2.

### 5.1.1.4 Deviations from FAO statistics

There are some differences between the number of animals used in these calculations and the FAO statistics. The general reason that animal statistics used in the emission inventory differ from the statistics delivered to FAO is that the statistics are used for different purposes. Animal statistics used in the inventory has to be categorized so that the categories fit the recommended methodology and the various emission factors used in the emission estimations. The figures reported to the FAO are provided by the Norwegian Institute of Bioeconomy Research (NIBIO)<sup>19</sup>. NIBIO makes an overall estimation for the agricultural sector, which is the basis for the annual negotiations for the economic support to the sector. This estimate includes a grouping of all agricultural activities, comprising area, number of animals and production data. Differences include:

<sup>18</sup> UMB (2001): Expert judgement by Department of Animal Science, Ås: Norwegian University of Life Sciences.

<sup>19</sup> Former named the Agricultural Economics Research Institute (NILF).

- Different emphasis on the dates for counting.
- NIBIO does not register pigs under 8 weeks, whilst Statistics Norway does. For the number of animals for slaughter, Statistics Norway uses the statistics of approved carcasses, which together with data on slaughter age gives a far better figure on estimated animal years (average population through the year) compared to figures for registered animals at specific dates which is used in the FAO statistics.
- For the number of dairy cows and heifers for replacement, Statistics Norway uses statistics from the Cow Recording System (TINE BA Annually), which is presumed to give a more accurate figure on number of animal years of dairy cows than the figures from Statistics Norway.

Emissions from other animal groups than included in the estimations (ostrich, donkey, lama and alpaca) are expected to be very small and decreasing. Emissions from ostrich have earlier been included in the estimations, but the number of ostriches has had a decreasing trend and are now very limited (39 in 2013). At the most the number of ostriches was 2113 in 1999. The total emissions from ostrich were less than 500 tonnes of CO<sub>2</sub> equivalents when the animal population was at its highest.

### 5.1.2 Nitrogen in animal manure as basis for emission estimates

Access to nitrogen is vital for all plant growth; hence nitrogen is added to the soil from i.e., animal manure. This causes emissions to air at various points of compounds containing nitrogen. Of the nitrogen compounds emitted to air from animal manure, N<sub>2</sub>O, NO<sub>x</sub> and NH<sub>3</sub> are estimated.

According to the IPCC and LRTAP guidelines, process emissions of nitrogen compounds from use of animal manure are calculated from the following sources:

- Manure management systems (N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub>)
- Application of manure on soil (N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub>)
- Droppings from animals on pastures (N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub>)
- Leakage of nitrogen through manure management systems and soils (N<sub>2</sub>O)
- Deposition of nitrogen from emissions of NH<sub>3</sub> and NO<sub>x</sub> (N<sub>2</sub>O)

Though the nitrogen flow is continuously depending on its surroundings (soil characteristics, temperature, moisture etc.) and the preceding supplies and losses of N, the emission estimates of each of the sources above are generally done independently of emissions from the other sources mentioned.

Figure 5-1 gives an overview of the manure nitrogen flows in the Norwegian greenhouse gas inventory.

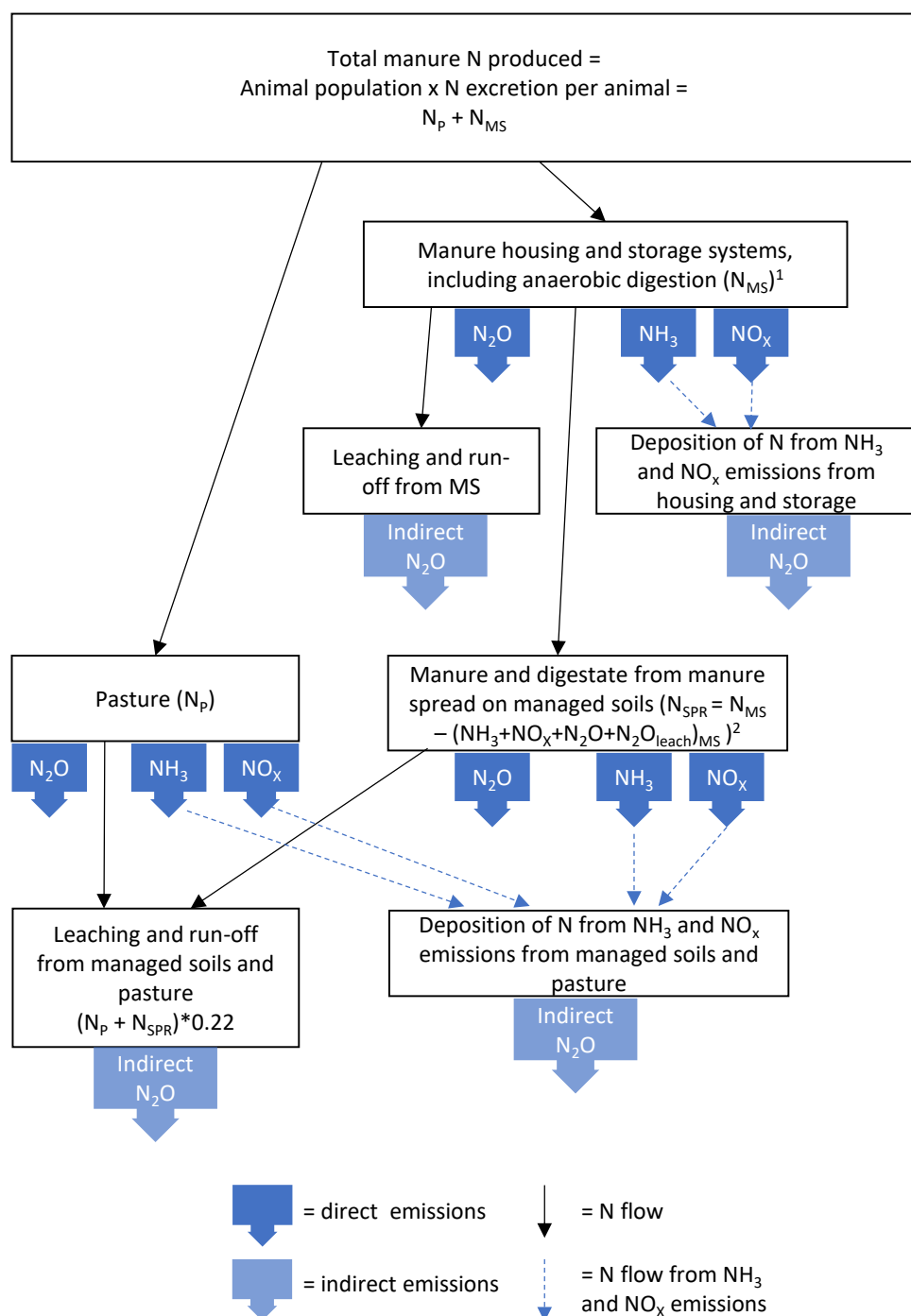
The Norwegian model for calculating agricultural manure nitrogen emissions to atmosphere is described in Carbon Limits (2020a).

The following decides the amounts of N that are used as the basis for the respective emission calculations:

- The amount of N in manure systems is calculated as total N in manure adjusted for the N that is dropped on pastures. In addition, the nitrogen added in bedding (applicable only to solid manure) is taken into account, and the consequent immobilization of TAN in that bedding, in line with (EEA 2019). The volumes of different bedding types used is based on Luostarinen et al. (2017). These volumes are converted into weights and thence tot-N added due to bedding as quoted in Grönroos et al. (2017).
- $\text{N}_2\text{O}$  emitted during spreading is calculated from the amounts of N in manure spread to land. This means that N lost through leaching in manure storage and as  $\text{N}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{NO}_x$  in manure housing and storage is deducted. However, N lost as  $\text{N}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{NO}_x$  during spreading, as well as indirect emissions of  $\text{N}_2\text{O}$  due to atmospheric deposition, are not deducted.
- $\text{NH}_3$  emitted during and after spreading of manure is based on the amounts of TAN in manure spread to land minus N lost through leaching in manure storage and as  $\text{N}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{NO}_x$  in manure housing and storage.  $\text{NO}_x$  emitted during and after spreading of manure also has the same basis. For  $\text{NH}_3$  emissions, N lost as  $\text{N}_2\text{O}$  and  $\text{NO}_x$  during spreading, as well as indirect emissions of  $\text{N}_2\text{O}$  due to atmospheric deposition is not deducted. Similarly, for  $\text{NO}_x$  emissions, N lost as  $\text{N}_2\text{O}$  and  $\text{NH}_3$  during spreading, as well as indirect emissions of  $\text{N}_2\text{O}$  due to atmospheric deposition is not deducted.
- Emissions of  $\text{N}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{NO}_x$  from pasture are calculated independently of each other and are based on the amounts of N (or TAN for  $\text{NH}_3$  emissions) estimated in manure dropped during grazing.
- $\text{N}_2\text{O}$  lost through leaching due to spreading is based on total N in manure spread to land minus N lost through leaching in manure storage and as  $\text{N}_2\text{O}$ ,  $\text{NH}_3$  and  $\text{NO}_x$  in manure housing and storage.  $\text{N}_2\text{O}$  lost through leaching due to grazing is based on total N excreted on pastures.  $\text{N}_2\text{O}$  lost through leaching during storage of manure is based on the amounts of N estimated for the particular management systems that are susceptible to leaching. N lost through emissions of  $\text{NH}_3$  from housing is not deducted.

- The nitrogen in  $\text{NH}_3$  and  $\text{NO}_x$  volatilized during housing, storage, pasture and spreading of manure is the basis for the calculation of  $\text{N}_2\text{O}$  emissions from atmospheric deposition. How the amounts of N are estimated in the various emission estimates, is described in more details in the respective chapters below.





<sup>1</sup> For estimation of  $NH_3$  and  $NO_x$  emissions from manure storage systems, emissions of  $NH_3$  from housing are deducted from N excreted in housing.  $N_2O$  emissions (direct and indirect) are estimated directly from N excreted in housing.

<sup>2</sup> Emissions of  $N_2O$ ,  $NH_3$  and  $NO_x$  that have occurred prior to spreading of manure on managed soils (during housing, storage and production of biogas) are deducted before emissions of  $N_2O$ ,  $NH_3$  and  $NO_x$  from application to soils are estimated.

Figure 5-1 Overview of the manure nitrogen flows in the Norwegian greenhouse gas inventory.

### 5.1.3 Sector specific QA/QC and verification

In 2019, a technical committee on agricultural greenhouse gas emission (Teknisk beregningsutvalg for klimagassutslipp i jordbruk) on behalf of the Ministry of Agriculture and Food, published its final report<sup>20</sup>. This document pointed out possible ways to improve the emission inventory to better reflect mitigation measures and where enhanced knowledge is needed. The Norwegian Government and the agricultural organisations have in 2019 entered into a letter of intent about reducing greenhouse gas emissions and increasing the carbon sink from agricultural activities with 5 million tonnes CO<sub>2</sub> equivalents for the period 2021-2030. As part of this deal, recommendations from the technical committee on agricultural greenhouse gas emission will be followed up on a yearly basis. In addition, information that can contribute to the improvement of the state of knowledge for activity data or emission factors in the national emission inventory will be pointed out/highlighted.

## 5.2 Emissions from enteric fermentation in domestic livestock - 3A (Key category for CH<sub>4</sub>)

### 5.2.1 Category description

An important end product from the ruminal fermentation is methane (CH<sub>4</sub>). The amount of CH<sub>4</sub> produced from enteric fermentation is dependent on several factors, like animal species, production level, quantity and quality of feed ingested and environmental conditions. According to IPCC the method for estimating CH<sub>4</sub> emissions from enteric fermentation requires three basic items:

- The livestock population must be divided into animal subgroups, which describe animal type and production level.
- Estimate the emission factors for each subgroup in terms of kilograms of CH<sub>4</sub> per animal per year.
- Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emissions, and sum across the subgroups to estimate total emission.

Enteric fermentation is a key category both for level and trend assessment.

Enteric fermentation contributed with 2557 ktonnes CO<sub>2</sub> equivalents in 2021, which is 54 percent of the GHG emissions from this sector. Emissions decreased by 5.4% in the period 1990-2021 and increased by 1.4% in 2020-2021.

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<sup>20</sup>[https://www.regjeringen.no/contentassets/0f1af0ca7efe493e8e48b46b6fba5ffd/rapport-tbu-jordbruk\\_siste.pdf](https://www.regjeringen.no/contentassets/0f1af0ca7efe493e8e48b46b6fba5ffd/rapport-tbu-jordbruk_siste.pdf)

### 5.2.1.1 Methodological issues

A Tier 2 methodology is used for calculating CH<sub>4</sub> from enteric fermentation for the main emission sources cattle and sheep.

The following basic equation is used to calculate the enteric CH<sub>4</sub> emission factor (IPCC 2006):

$$EF = (GE \times Y_m \times 365 \text{ days/yr}) / 55.65 \text{ MJ/kg CH}_4$$

Where:

EF = emission factor, kg CH<sub>4</sub>/head/yr

GE = gross energy intake, MJ/head/day

This equation assumes an emission factor for an entire year (365 days). In some circumstances the animal category may be alive for a shorter period or a period longer than one year and in this case the emission factor will be estimated for the specific period (e.g., lambs living for only 143 days and for beef cattle which are slaughtered after around 540 days, varying from year to year).

For dairy cattle gross energy intake, GE and the methane conversion rate, Y<sub>m</sub> are based on annual figures for milk yield and the percentage of concentrate in the diet. The Tier 2 methodology used for mature dairy cattle is presented more in detail in a note by Prestløkken & Schwarm (2019) published in NIR 2020, Annex IX, section 2.2.

For beef cattle the emission factor is based on recent studies from herds reflecting the variation in breeds, feeding practice and geography for beef cattle management in Norway. The method assumes that there are small annual variations in feeding practice and annual emissions depends on number of animals. The method is presented further in Aspeholen Åby et al. (2018) published in NIR 2019, Annex IX, section 2.2.2.

For young cattle the annual variations in emissions are based on slaughter weight, slaughter age and the number of animals. The methodology is described in Storlien and Harstad (2015) published in NIR 2019 Annex IX, section 2.2.1.

The methodology used for sheep was developed in 2006 and is based on the tier 2 method described by IPCC (method presented more in detail in a note by Volden and Nes (2006), revised version published in NIR 2019 Annex IX, section 2.2.3). The number of animals for the different subgroups of sheep and carcass weight by slaughter are updated every year. The methodology for calculating CH<sub>4</sub> from enteric fermentation for the other animal

categories is in accordance with the Tier 1 method from the IPCC guidelines (IPCC 2006). The numbers of animals of each category and average emission factors of tonnes CH<sub>4</sub> per animal and year for each category of animals are used to calculate the emissions.

The model used to estimate enteric fermentation from the Norwegian agriculture is described in more detail in (Carbon Limits 2021).

#### 5.2.1.2 Activity data

Emissions are estimated from the animal population. How the animal population is estimated is described in Section 5.1.1 and Annex VIII.

The Tier 2 method of calculation which is implemented for cattle and sheep requires subdividing the cattle and sheep populations by animal type, physiological status (dry, lactating, or pregnant) live weight and age. Table 5.5 describes the animal categories used for cattle and sheep in the calculations, and Table 5.6 gives important input parameters in the estimations of enteric methane from cattle.

**Table 5.5 Categories of cattle and sheep used in the Norwegian calculations of methane emission from enteric fermentation.**

| Categories of cattle and sheep                    |
|---------------------------------------------------|
| Dairy cows                                        |
| Beef cows                                         |
| Replacement heifers                               |
| Finisher heifers, < one year at time of slaughter |
| Finisher heifers, > one year at time of slaughter |
| Finisher bulls, < one year at time of slaughter   |
| Finisher bulls, > one year at time of slaughter   |
| Breeding sheep, > one year                        |
| Breeding sheep, < one year                        |
| Slaughter lamb, < one year. Jan- May              |
| Slaughter lamb, < one year. Jun- Dec              |

#### 5.2.1.3 Emission factors

##### Dairy cattle

For the yearly update of the emission factor for dairy cattle we need information about milk yield and proportion of concentrate in the diet.

The model used for predicting methane emission from dairy cattle at national level is based on calculations in the feed ration program NorFor (NorFor-data), using steps of 500 kg energy corrected milk (ECM), in the range 5000 to 12000 kg ECM. The data predict feed rations during a 305-day lactation and includes most rations commonly used to feed dairy cows in Norway. Based on the equation

$$\text{CH}_4 \text{ (MJ/d)} = 1.16 \times \text{DMI} - 0.110 \times \text{FA content} + 0.0106 \times \text{NDF content}$$

DMI = dry matter intake, kg/day

FA = fatty acids, g/kg DM

NDF= neutral-detergent fibre, g/kg DM.

a regression analysis has been performed which gave a regression equation for methane emissions based on 305 day milk yield and concentrate share of the diet.

The equations are:

$$\text{GE} = 137.9 + 0.0249 \times \text{Milk}_{305} + 0.2806 \times \text{Concentrate\_proportion}$$

GE = gross energy intake, MJ/day

Milk<sub>305</sub> = 305 d lactation yield of ECM

Concentrate\_proportion = proportion of concentrate in the total diet on net energy basis, %

and

$$\text{Y}_m = 7.38 - 0.00003 \times \text{Milk}_{305} - 0.01758 \times \text{Concentrate\_proportion}$$

Y<sub>m</sub> = methane conversion rate, %

Milk<sub>305</sub> = 305 d lactation yield of ECM

Concentrate\_proportion = proportion of concentrate in the total diet on net energy basis, %

| Table 5.6 Important parameter inputs in the calculations of GE and Y <sub>m</sub> for dairy cows. |                                                    |                                                                      |
|---------------------------------------------------------------------------------------------------|----------------------------------------------------|----------------------------------------------------------------------|
|                                                                                                   | Annual milk production, dairy cows. kg/animal/year | Proportion of feed concentrate in the rations of mature dairy cows.% |
| 1990                                                                                              | 6 320                                              | 39.1                                                                 |
| 1995                                                                                              | 6 326                                              | 36.8                                                                 |
| 2000                                                                                              | 6 156                                              | 36.4                                                                 |
| 2005                                                                                              | 6 723                                              | 37.7                                                                 |
| 2009                                                                                              | 7 276                                              | 40.1                                                                 |
| 2010                                                                                              | 7 373                                              | 41.0                                                                 |
| 2011                                                                                              | 7 309                                              | 41.9                                                                 |
| 2012                                                                                              | 7 475                                              | 42.9                                                                 |
| 2013                                                                                              | 7 691                                              | 42.5                                                                 |
| 2014                                                                                              | 7 711                                              | 43.3                                                                 |
| 2015                                                                                              | 7 958                                              | 43.3                                                                 |
| 2016                                                                                              | 8 062                                              | 43.3                                                                 |
| 2017                                                                                              | 7 902                                              | 44.2                                                                 |
| 2018                                                                                              | 7 840                                              | 45.6                                                                 |
| 2019                                                                                              | 8 395                                              | 45.6                                                                 |
| 2020                                                                                              | 8 463                                              | 45.4                                                                 |
| 2021                                                                                              | 8 489                                              | 45.2                                                                 |

Source: Cow Recording System (TINE BA Annually)

Further description of the determination of the variables GE and Y<sub>m</sub> for dairy cattle are given in NIR 2020, Annex IX, section 2.2. Values for GE and Y<sub>m</sub> used in the estimations are given in NIR 2023 Annex VIII, section 2.1.

### Beef cow

Based on data on feed management practices in Norwegian commercial beef cow herds a country-specific Tier 2 method has been developed for the estimation of enteric CH<sub>4</sub> emissions from beef cows. The data included 31 commercial beef cow herds keeping the main beef breeds in Norway, where individual feed intake had been estimated for all mature beef cows in the herds. Average daily dry matter (DM) intake per beef cow and proportion of various feed stuffs in the feed ration (% of DM) in the included herds was given.

The CH<sub>4</sub> conversion rate, Y<sub>m</sub>, was adjusted to account for the digestibility of the dietary dry matter (DE):

$$Y_m = 0.1058 - 0.0006 \times DE$$

Based on this information an average GE and  $Y_m$  factor for Norwegian beef cows was estimated.

| <b>Table 5.7 Norwegian values for GE and <math>Y_m</math> for beef cows</b> |         |                              |
|-----------------------------------------------------------------------------|---------|------------------------------|
| GE intake MJ/day                                                            | $Y_m\%$ | Methane kg per head and year |
| 194                                                                         | 6.82    | 86                           |

*Source: Aspehølen Åby et al. (2017) published in NIR 2019, Annex IX, section 2.2.2*

Further description of the determination of the variables GE and  $Y_m$  for beef cow and the values used in the calculations are given in NIR 2019, Annex IX, section 2.2.2. The method is based on data from one year, and there have been some changes in the composition of the breed of the beef population in Norway since 1990. But we lack data for a good variable that we could use to get a trend for GE and  $Y_m$  for beef cow. Since the change in the composition of the population has been an increase of heavier breed, this can mean that there is an overestimation of the emissions for the earlier years. This is expected to be a minor source of error, since the population of beef cow was of less significance earlier.

#### Young cattle

The following equation was used to predict enteric  $CH_4$  production from young cattle:

$$CH_4 \text{ (GE Mcal/day)} = -0.056 + 0.0447 \times GEI + 0.0039 \times NDF - 0.033 \times EE + 0.00141 \times BW$$

GEI = gross energy intake (Mcal/day)

NDF = neutral-detergent fiber, percent in diet, DM basis

EE = ether extract, percent in diet, DM basis

BW = body weight, kg

Based on standard feed rations, daily intake of GE and  $Y_m$  for the different categories of young cattle were predicted. From the data set a multiple regression analysis were accomplished to develop equations that predict GE and  $Y_m$  from animal characteristics available for replacement heifers, growing and finishing cattle (bulls and heifers).

The following equations were developed to predict daily intake of GE:

$$\text{Slaughtered } < 1 \text{ year: } GE = 38.95 + 1.0558 \times CAW - 6.96 \times SLA$$

$$\text{Slaughtered } > 1 \text{ year: } GE = 112.99 + 0.3495 \times CAW - 4.696 \times SLA$$

GE = gross energy intake, MJ/d

CAW = carcass weight, kg

SLA = months of slaughter

The following equations were developed to predict  $Y_m$  for growing and finishing cattle:

Slaughtered < 1 year:  $Y_m = 5.19 - 0.00482 \times CAW + 0.1465 \text{ SLA}$

Slaughtered > 1 year:  $Y_m = 5.04 - 0.0054 \times CAW + 0.1453 \times SLA$

$Y_m$  = methane conversion rate, %

CAW = carcass weight, kg

SLA = months of slaughter

The same approach was used when predicting enteric  $\text{CH}_4$  emissions from replacement heifers. Standard rations for the replacement heifers were calculated for age at calving of 24 and 26 months. Within age at calving, three live weights were used; 500, 530 and 560 kg. The following equation was developed to predict daily intake of GE:

$GE = 85.43 + 0.1942 \times LW - 1.83 \times AAC$

GE = gross energy intake, MJ/d

LW = live weight, kg

AAC = age at calving, months

The following equation is used to predict  $Y_m$  for replacement heifers:

$Y_m = 4.08 + 0.0032 \times LW + 0.0447 \times AAC$

$Y_m$  = methane conversion rate, %

LW = live weight, kg

AAC = age at calving, months



**Table 5.8 Important parameter inputs in the calculations of methane emissions from cattle over 1 year.**

|      | Carcass weight at time of slaughter, heifer > 1 year. kg | Age at time of slaughter, heifers > 1 year. Months | Carcass weight at time of slaughter, bulls > 1 year. Kg | Age at time of slaughter, bulls > 1 year. Months |
|------|----------------------------------------------------------|----------------------------------------------------|---------------------------------------------------------|--------------------------------------------------|
| 1990 | 185                                                      | 21.6                                               | 255                                                     | 19.7                                             |
| 1995 | 200                                                      | 22.2                                               | 276                                                     | 19.7                                             |
| 2000 | 202                                                      | 22.3                                               | 269                                                     | 18.8                                             |
| 2005 | 216                                                      | 22.8                                               | 296                                                     | 19.0                                             |
| 2009 | 219                                                      | 22.8                                               | 301                                                     | 18.0                                             |
| 2010 | 221                                                      | 22.8                                               | 302                                                     | 18.0                                             |
| 2011 | 210                                                      | 22.5                                               | 297                                                     | 17.7                                             |
| 2012 | 205                                                      | 22.7                                               | 294                                                     | 17.7                                             |
| 2013 | 209                                                      | 22.8                                               | 298                                                     | 17.5                                             |
| 2014 | 244                                                      | 22.8                                               | 302                                                     | 17.3                                             |
| 2015 | 256                                                      | 23.2                                               | 310                                                     | 17.4                                             |
| 2016 | 260                                                      | 23.2                                               | 317                                                     | 18.2                                             |
| 2017 | 251                                                      | 23.0                                               | 313                                                     | 18.4                                             |
| 2018 | 233                                                      | 22.2                                               | 306                                                     | 18.0                                             |
| 2019 | 236                                                      | 22.4                                               | 313                                                     | 17.9                                             |
| 2020 | 225                                                      | 22.5                                               | 318                                                     | 17.9                                             |
| 2021 | 229                                                      | 22.4                                               | 322                                                     | 18.07                                            |

Source: Estimations by Statistics Norway

**Table 5.9 Important parameter inputs in the calculations of methane emissions from cattle under 1 year.**

|      | Heifers < 1 year.<br>Carcass weight | Heifers < 1 year.<br>Average age, months | Bulls < 1 year.<br>Carcass weight | Bulls < 1 year.<br>Average age, months |
|------|-------------------------------------|------------------------------------------|-----------------------------------|----------------------------------------|
| 1990 | 56                                  | 6.5                                      | 75.8                              | 6.4                                    |
| 1995 | 70                                  | 7.0                                      | 93.8                              | 6.9                                    |
| 2000 | 65                                  | 6.0                                      | 82.0                              | 5.9                                    |
| 2005 | 93                                  | 7.9                                      | 115.6                             | 7.5                                    |
| 2009 | 93                                  | 8.0                                      | 118.4                             | 7.6                                    |
| 2010 | 93                                  | 8.1                                      | 116.1                             | 7.5                                    |
| 2011 | 95                                  | 8.2                                      | 117.6                             | 7.5                                    |
| 2012 | 96                                  | 7.9                                      | 119.7                             | 7.6                                    |
| 2013 | 102                                 | 8.2                                      | 122.5                             | 7.6                                    |
| 2014 | 106                                 | 8.2                                      | 124.5                             | 7.5                                    |
| 2015 | 107                                 | 8.2                                      | 125.5                             | 7.5                                    |
| 2016 | 105                                 | 7.9                                      | 126.6                             | 7.5                                    |
| 2017 | 103                                 | 8.2                                      | 125.9                             | 7.6                                    |
| 2018 | 91                                  | 8.0                                      | 129.0                             | 7.1                                    |
| 2019 | 110                                 | 8.3                                      | 131.2                             | 7.7                                    |
| 2020 | 110                                 | 8.4                                      | 132.3                             | 7.8                                    |
| 2021 | 113                                 | 8.4                                      | 132.4                             | 7.8                                    |

Source: Cow Recording System (**TINE BA Annually**) and estimations by Statistics Norway (values were amended during the 2021 revision of the model)

Further description of the determination of the variables GE and  $Y_m$  for young cattle are given in NIR 2019, Annex IX, section 2.2.1. Values for GE and  $Y_m$  used in the estimations are given in NIR 2023, Annex VIII, section 2.1.

### Sheep

Prediction of methane emission from sheep is based on the intake of GE and the fraction of GE converted to  $CH_4$  (the  $CH_4$  conversion rate,  $Y_m$ ). For the subgroups of sheep default values for  $Y_m$  from IPCC (2006) are used in the emission estimations. Gross energy intake (GE) is estimated from the net energy requirements (NE) and conversion factors from net energy to GE, according to the equation 10.16 in the IPCC Guidelines (IPCC 2006).

**Table 5.10 Important parameter inputs in the calculations of methane emissions from sheep. 2021.**

|                               | Carcass weight. kg | Age at slaughter. Months | Conversion factor for methane, Y <sub>m</sub> .% |
|-------------------------------|--------------------|--------------------------|--------------------------------------------------|
| Breeding sheep > 1 year       | 31                 | NA                       | 6.5                                              |
| Breeding sheep < 1 year       | 29                 | 12                       | 4.5                                              |
| Lamb for slaughter, Jan.-May  | 19.3               | 11                       | 4.5                                              |
| Lamb for slaughter, June-Dec. | 18.6               | 4.7                      | 4.5                                              |

Source: Carcass weight from slaughter statistics, Statistics Norway, age at slaughter from Volden and Nes, 2006, see NIR 2019 Annex IX section 2.2.3. Y<sub>m</sub> from IPCC (2006). Values for carcass weight are annual.

In Table 5.10 the carcass weights are updated annually except for Breeding sheep < 1 year which is kept constant. The ages and Y<sub>m</sub> are also constant figures.

Further description of the determination of the GE values for the different groups of sheep is given in NIR 2019, Annex IX, section 2.2.3. Values for GE and Y<sub>m</sub> used in the estimations for sheep are given in NIR 2023 Annex VIII, section 2.1.

The emissions from hens and pullets, domestic reindeer, deer and fur-bearing animals are also included in the Norwegian calculations. The Norwegian University of Life sciences has investigated and documented the national emission factors for poultry. Only hens and pullets have emissions of significance (Svihus 2015). For reindeer the emission factor 14.0 kg/animal/year is used and for deer 20.0 kg/animal/year. Both factors are expert judgments from the University of Life Sciences (Karlengen et al. 2012) and have been estimated based on the methodology described for cervidae in IPCC (2006). Danish emission factors are used for goat since they are considered to reflect Norwegian feed intake and circumstances (Karlengen et al. 2012). Emission factor for fur-bearing animals has been developed by scaling emission factor for pigs, which are assumed most similar with regard to digestive system and feeding. The scaling is done by comparing average weights for fur-bearing animals and pigs and the factor is set to 0.1 kg/animal/year.

For the other animal categories, the Tier 1 default emission factors for each kind of animal (IPCC 2006) is used. The factors used are shown in Table 5.11.

| <b>Table 5.11 Emission factors for CH<sub>4</sub> from enteric fermentation and different animal types estimated with the Tier 1 method</b><br><b>Source: IPCC (2006), Karlengen et al. (2012), Svihus (2015).</b> |                                      |                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|-------------------------------|
| Animal                                                                                                                                                                                                             | Emission factor (Tonnes/animal/year) | Source                        |
| Horses                                                                                                                                                                                                             | 0.018                                | (IPCC 2006)                   |
| Goats                                                                                                                                                                                                              | 0.013                                | (Karlengen et al. 2012)       |
| Pigs                                                                                                                                                                                                               | 0.0015                               | (IPCC 2006)                   |
| Hens                                                                                                                                                                                                               | 0.00002                              | (Svihus 2015)                 |
| Pullets                                                                                                                                                                                                            | 0.0000036                            | (Svihus 2015)                 |
| Reindeer                                                                                                                                                                                                           | 0.014                                | (Karlengen et al. 2012)       |
| Deer                                                                                                                                                                                                               | 0.02                                 | (Karlengen et al. 2012)       |
| Fur-bearing animals                                                                                                                                                                                                | 0.0001                               | Estimate by Statistics Norway |

Source: IPCC (2006), Karlengen et al. (2012), Svihus (2015).

## 5.2.2 Uncertainties and time-series consistency

### 5.2.2.1 Activity data

The data is considered to be known within  $\pm 5\%$ . There is also uncertainty connected to the fact that some categories of animals are only alive part of the year and the estimation of how long this part is.

### 5.2.2.2 Emission factors

Although the emissions depend on several factors and therefore vary between different individuals of one category of animal, average emission factors for each category are used in the tier 1 methodology for all animal categories except cattle and sheep, where a tier 2 methodology is used.

The standard deviation of the emission factors is considered to be  $\pm 40\%$ , which is the estimate from the IPCC guidelines (IPCC 2006). An uncertainty estimate of  $\pm 28\%$  for dairy cows (Prestløykken & Schwarm 2019),  $\pm 20\%$  for beef cows (IPCC 2006) and  $\pm 25\%$  for other cattle and sheep in the Tier 2 methodology (Storlien & Harstad 2015).

## 5.2.3 Category specific QA/QC and verification

In 2001, a project was initiated to improve the estimate of the exact number of animal populations. This was completed in 2002. In 2012, a further revision of the numbers of bulls and heifers was implemented. The revised data on animal populations form the basis for the emission calculations for all years. In 2005-2006, Statistics Norway and the Climate and Pollution Agency carried out a project in cooperation with the Norwegian University of Life Sciences, which resulted in an update of the emission estimations for cattle and sheep

using a tier 2 method. In 2015, the equations of this model were updated for cattle based on Norwegian data from the Cow recording system/NorFor (Storlien & Harstad 2015).

The Norwegian University of Life sciences has further investigated and documented the national emission factor of 20 g CH<sub>4</sub> per head used for laying hens in a project in 2015 (Svihus 2015). New emission factors for poultry in Norway were estimated in Svihus (2015). Only hens and pullets have measurable emissions. In the previous submissions, only hens and turkeys were considered. The new emissions factors have increased total emissions from poultry between 1 and 10 tonnes of CH<sub>4</sub> per year. Total emissions were 98 tonnes in 2015, which shows this an insignificant source of CH<sub>4</sub> emissions.

In 2015, a project at the Norwegian University of Life sciences (NMBU) investigated the basic equations used to calculate the emission factors for enteric methane for cattle in the tier 2 methodology. The results of this project were implemented in the 2016 submission. In 2019, NMBU has updated the model for calculating the enteric methane from dairy cattle. As part of the project a literature study and an evaluation of different existing models was made. The results from this study are presented more in detail in a note by Prestløkken & Schwarm (2019) in NIR 2020, Annex IX, section 2.2.

A literature study was performed in 2019, where emission factors for estimating enteric methane from sheep in scientific publications was investigated. In the study, comparison with the emission factors used in other countries (Ireland, Sweden, Denmark, Greenland, and New Zealand) was also made. The study concluded that it does not seem necessary with an update of the Norwegian methodology for estimating enteric methane from sheep (Haarsaker & Een Thuen 2019).

In 2021, a technical revision of the model calculations of enteric methane was performed by Carbon Limits in close cooperation with the Norwegian University of Life Sciences (NMBU) (Carbon Limits 2021). The enteric fermentation model has been aligned with the outline and design of the manure models used in the inventory, and user input has been simplified. At the same time NMBU have reviewed the emission factors and the methodology used for all animal categories. Some minor adjustments in several underlying parameters used to calculate gross energy intake for sheep have been suggested and implemented in the updated model for calculation of emissions from enteric fermentation.

### 5.2.4 Category-specific recalculations

No methodological changes were introduced in submission 2023 for enteric fermentation. However, a change in the animal weight for young cattle in 2020 led to 1 per cent higher emission, and revised animal number for sheep resulted in 2 per cent higher emission of enteric methane compared to earlier submission.

### 5.2.5 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 5.3 Emissions from manure management - 3B (Key categories for CH<sub>4</sub> and N<sub>2</sub>O)

### 5.3.1 Category description

The relevant greenhouse gases emitted from this source category are CH<sub>4</sub> (IPCC 3Ba) and N<sub>2</sub>O (IPCC 3Bb). Emissions from cattle are most important in Norway for both components. Both CH<sub>4</sub> emissions from cattle manure management and N<sub>2</sub>O emissions from manure management are key category according to the Approach 2 key category analysis.

CH<sub>4</sub> emissions due to manure management amounted to 406 ktonnes CO<sub>2</sub> equivalents in 2021 whilst N<sub>2</sub>O emissions amounted to 145 ktonnes CO<sub>2</sub> equivalents.

Manure management emitted 551 ktonnes of CO<sub>2</sub> equivalents in 2021, which are approximately 12% of the GHG emissions from agriculture.

Emissions of GHGs from manure management increased by 8.0% in the period 1990-2021 and increased by 1.5% from 2020 to 2021.

Organic material in manure is transformed to CH<sub>4</sub> in an anaerobic environment by microbiological processes. Emissions from cattle (manure) are most important in Norway. The emissions from manure depend on several factors: type of animal, feeding, manure management system and weather conditions (temperature and humidity).

During storage and handling of manure, including use of manure for biogas production (i.e., before the manure is added to soils), some nitrogen is converted to N<sub>2</sub>O. The fraction converted to N<sub>2</sub>O depends on the system and duration of manure management. Liquid system is the most widespread storage system, and consequently the most important

source. Indirect emissions of  $\text{N}_2\text{O}$  (atmospheric deposition and leaching) from manure storage are also estimated.

Emissions of  $\text{NH}_3$  from manure depend on several factors, e.g., type of animal, nitrogen content in fodder, manure management, climate, time of spreading of manure, cultivation practices and characteristics of the soil. In the Norwegian emission inventory, yearly updated estimations for  $\text{NH}_3$  volatilisation from manure are used. Like for  $\text{NH}_3$ , emissions of  $\text{NO}_x$  from animal manure led to indirect emissions of  $\text{N}_2\text{O}$  from deposition. The amounts of N from  $\text{NO}_x$  emissions from manure management systems, spreading of manure and droppings on pastures are however small.

Section 5.1.2 gives more information about nitrogen in animal manure as basis for emission estimates and an overview of the manure nitrogen flows in the Norwegian greenhouse gas inventory.

#### **5.3.1.1 Methodological issues**

##### **5.3.1.1.1 $\text{CH}_4$**

Emissions of methane are estimated using a model based on a stepwise approach which is illustrated in Figure 5-2.

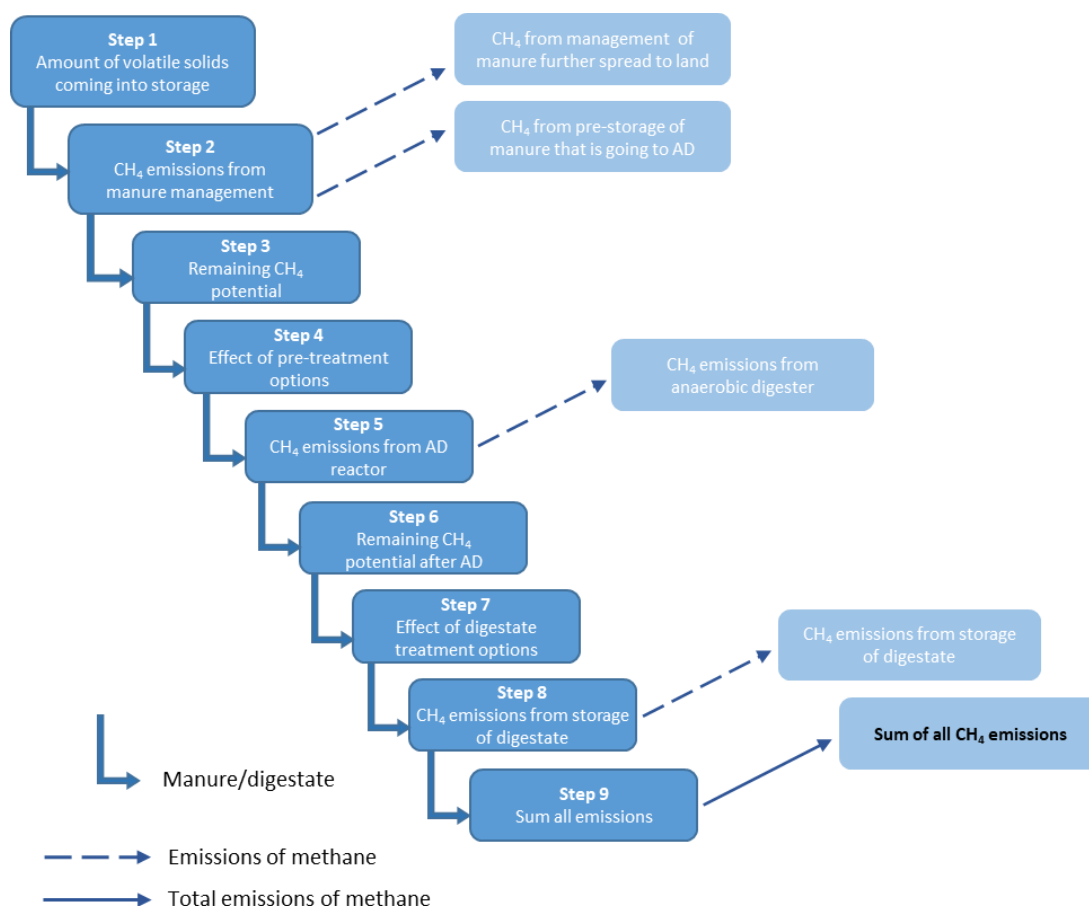


Figure 5-2 Summary of the stepwise approach of the model

The model estimates emissions of methane from both management of manure that is further spread to land and from storage of manure prior to further treatment, specifically through anaerobic digestion (AD). The model determines methane emissions based on animal category, the share of different manure type (slurry, deep litter and solid manure), the share of the different options for the manure management system (MMS, e.g., manure cellar under slatted floor, manure cellar under solid floor, manure tank with tight roof) and the downstream fate of the manure (i.e., spread to land or anaerobic digestion).

The model is primarily based on IPCC 2006 Guidelines, in particular with respect to emissions from the majority of MMS options, with a special approach developed for quantifying methane emissions from AD. In Norway, there are currently only a few farm-fed AD plants.



For all animal categories emissions of methane from manure management are estimated using the equations presented below, in accordance with the IPCC Tier 2 method (IPCC 2006). The use of the Tier 2 method in the model results in a more consistent approach to estimation of CH<sub>4</sub> emissions from manure management systems in Norway, as well as better reflects the national manure management practices applied.

CH<sub>4</sub> Emissions = EF \* Population

$$EF_i = VS_i * 365 \text{ days/year} * Bo_i * 0.67 \text{ kg/m}^3 * \sum_{(j,k)} MCF_{jk} * MS_{ijk}$$

EF<sub>i</sub> = annual emission factor for defined livestock population *i*, in kg

VS<sub>i</sub> = daily VS excreted for an animal within defined population *i*, in kg

Bo<sub>i</sub> = maximum CH<sub>4</sub> producing capacity for manure produced by an animal within defined population *i*, m<sup>3</sup>/kg of VS

MCF<sub>jk</sub> = CH<sub>4</sub> conversion factors for each manure management system *j* by climate region *k*

MS<sub>ijk</sub> = fraction of animal species/category *i*'s manure handled using manure system *j* in climate region *k*

The factors VS, B<sub>0</sub> and MCF are average factors meant to represent the whole country.

The model includes a total of nine steps<sup>21</sup>. Step 1 determines the total amount of volatile solids (VS) which enters the MMS. Step 2 determines the emissions from storage of manure that is further spread to land, as well as emissions from pre-storage of manure that is then further treated by anaerobic digestion (either at the farm itself or at an off-site facility).

Step 2 therefore estimates a "sub-total" of emissions of methane, namely methane emissions from storage of manure which is further spread to land and emissions of methane from pre-storage of manure that is sent for anaerobic digestion. The methane emissions from storage as calculated in the step 2 reduce the CH<sub>4</sub> production of any manure going to an AD reactor (including the pre-treatment). Step 3 therefore estimates the remaining methane potential after storage of manure prior to AD. Step 4 is used to estimate the effect of various pre-treatment options (if any) on the overall methane potential of the manure going to AD. Step 5 estimates emissions from the AD reactor ("sub-total" of emissions of methane from AD). As in step 3, the methane emissions from the AD phase as calculated in step 5 significantly reduce the CH<sub>4</sub> production potential of the digestate. Step 6 therefore estimates the remaining methane potential of the digestate after AD. Step 7 estimates the remaining methane potential after digestate treatment (if any). Step 8 estimates emissions of methane from storage of digestate, resulting in the final "sub-total" of emissions of methane. In step 9 all "sub-totals" of emissions of methane summarized and summed.

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<sup>21</sup> A technical description of the model is available in: "Greenhouse gas emissions from biogas production from manure in Norwegian agriculture", Carbon Limits (2020b)

The populations of animals are consistent with the animal data used elsewhere in the inventory (see chapter 5.1.1 and Annex VIII for further details). For young cattle, this implies that the VS production is estimated for the whole average lifetime/time until first calving and not per animal year. The amount of volatile solids (VS) for other cattle is estimated directly as kg/animal/year. The VS factors are based on the same data sources used in the estimations of nitrogen excretion factors, that are used in estimations of N<sub>2</sub>O from manure (Karlengen et al. 2012; Volden 2022). For beef cows, national factors for VS and nitrogen excretion factors were estimated by the Norwegian University of Life Sciences (NMBU) in 2018. National feeding data for beef cow under Norwegian circumstances from Wetlesen et. al. (2018), the same as used for the estimation of enteric methane, has been used as a basis for the estimations. The method is described more in detail in Aspehølen Åby et al. (2018), (published in NIR 2019, Annex IX, section 4). For swine and poultry, country specific estimates of NMBU for the percentage of the manure in dry matter that are volatile solids are used. Background data used for the estimations of VS are given in Table 5.12 and in Annex VIII. VS excretion rates for other animal categories (sheep, goats, horses, fur farming animals, deer, and reindeer) were based on a national study, where the dry matter excretion values were calculated using the IPCC 2006 Guidelines and VS share of dry matter was assessed using expert judgement (Morken, 2013<sup>22</sup>).

The factor B<sub>0</sub> represents the maximum potential production of methane under optimum conditions. For dairy cows, the B<sub>0</sub> factors are based on Norwegian research and for pigs the factor is based on literature studies (Morken et al. 2013), for other cattle, poultry, sheep, goats, horses, fur-farming animals, deer and reindeer the default IPCC factors are used.

| <b>Table 5.12 Norwegian factors for amount of manure (in dry matter - DM), VS and Bo used to estimate CH<sub>4</sub> from manure management with the IPCC Tier 2 method. 2021.</b> |               |            |     |                   |                   |      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|------------|-----|-------------------|-------------------|------|
|                                                                                                                                                                                    | Manure        |            | VS% | VS, kg per animal | VS, total, tonnes | Bo   |
|                                                                                                                                                                                    | kg DM/ animal | kg DM/ day |     |                   |                   |      |
| Non-Dairy Cattle                                                                                                                                                                   | --            | --         | --  |                   |                   |      |
| Beef cows                                                                                                                                                                          | --            | --         | --  | 1461              | 154 986           | 0.18 |
| Replacement heifer                                                                                                                                                                 | --            | --         | --  | 616               | 69 341            | 0.18 |
| Finisher heifer                                                                                                                                                                    | --            | --         | --  | 1323              | 42 257            | 0.18 |
| Finisher bulls                                                                                                                                                                     | --            | --         | --  | 972               | 152 901           | 0.18 |
| Dairy cows                                                                                                                                                                         | --            | --         | --  | 2 036             | 400 956           | 0.23 |

<sup>22</sup> Morken (2013) Revision of the Norwegian model for estimating methane emission from manure management

|                                               |        |      |     |        |         |      |
|-----------------------------------------------|--------|------|-----|--------|---------|------|
| Poultry                                       |        |      |     |        |         |      |
| Hens                                          | 13.15  | --   | 0.9 | 11.83  | 55 229  | 0.38 |
| Chicks bred for laying hens, animal places    | 3.10   | --   | 0.9 | 2.79   | 1 684   | 0.36 |
| Chicks for, slaughter animal places           | 4.08   | --   | 0.9 | 3.67   | 40 872  | 0.36 |
| Ducks for breeding                            | 30.00  | --   | 0.9 | 27.9   | 51      | 0.36 |
| Ducks for slaughter, animal places            | 8.12   | --   | 0.9 | 7.31   | 356     | 0.36 |
| Turkey and goose for breeding                 | 30.00  | --   | 0.9 | 27.9   | 289     | 0.36 |
| Turkey and goose for slaughter, animal places | 17.23  | --   | 0.9 | 15.51  | 5 720   | 0.36 |
| Swine                                         |        |      |     |        |         |      |
| Piglets 4-10 weeks                            | 18.41  | --   | 0.9 | 16.57  | 3 938   | 0.30 |
| Young pigs for breeding                       | 113.00 | --   | 0.9 | 101.70 | 3 417   | 0.30 |
| Pigs for slaughter, animal places/årsdyr      | 131.34 | --   | 0.9 | 118.21 | 53 925  |      |
| Sows                                          | 307.90 | --   | 0.9 | 277.11 | 10 884  | 0.30 |
| Boar                                          | 307.90 | --   | 0.9 | 277.11 | 245     | 0.30 |
| Sheep                                         | --     | 0.33 | 0.9 |        | 136 050 | 0.19 |
| Goats                                         | --     | 0.38 | 0.9 | 123    | 7 451   | 0.18 |
| Horses                                        | --     | 4.65 | 0.9 | 1 528  | 127 649 | 0.30 |
| Fur farming                                   | --     | 0.14 | 0.9 | 45     | 412     | 0.25 |
| Deer                                          | --     | 2.42 | 0.9 | 795    | 6 600   | 0.19 |
| Reindeer                                      | --     | 0.43 | 0.9 | 141    | 30 068  | 0.19 |

Sources: Manure, dry matter/animal, poultry and swine: Karlengen et al. (2012), Manure, dry matter/day, sheep, goats, horses, fur farming, deer and reindeer: Morken et al. (2013), VS%, Sheep, goats, horses, fur farming, deer and reindeer: Morken et al. (2013), poultry: expert estimate Birger Svihus NMBU, email 03.01.2013, swine: expert estimate Nils Petter Kjos, NMBU, email 03.01.2013. VS per animal, dairy cows:: Estimates based on Karlengen et al. (2012), beef cows: Aspeholen Åby et al. (2018), young cattle: Volden (2022). B0: Non-dairy cattle, poultry, sheep, goats, horses, fur farming, deer and reindeer: IPCC (2006); Dairy cows, swine: Morken et al. (2013)

Updated national MCF for liquid manure was developed and the specific manure management system distribution for each animal category in Norway (based on manure surveys) was taken into account for all animal categories. National unabated MCF for liquid manure has been developed using the methodology outlined by Andrew Vander Zaag (2018)<sup>23</sup>. A separate spreadsheet takes into account average annual temperatures in various regions of Norway, the frequency of manure removal from storage (on a monthly

<sup>23</sup> Andrew Vander Zaag (2018) MCF Calculations and Example Spreadsheet

scale), and the relative share of manure deposited in each of the regions in order to estimate weighted average national MCF. After a weighted average unabated MCF for liquid slurry has been developed, assumptions on emission reduction efficiency of different types of storage covers were made based on expert opinion and recommendations from the IPCC 2019 Refinement to derive MCFs for specific storage categories<sup>24</sup>. MCFs for storage of solid manure (deep litter and solid manure) were based on default IPCC factors (IPCC 2019). MCFs for poultry were assumed constant irrespective of storage or manure type, according to a default IPCC factor. A summary of the values for MCF according to animal category, manure type and manure management system is presented in [Table 5.13](#).

**Table 5.13 MCF according to animal category, manure type and manure management system. 2021.**

| Animal category             | Manure type                          | MMS                       | 2021   |
|-----------------------------|--------------------------------------|---------------------------|--------|
| Mature Dairy Cattle         | Slurry<br>Deep litter & solid manure | Liquid system             | 11.84% |
|                             |                                      | Solid storage and dry lot | 10.78% |
|                             | Pasture                              | Pasture range and paddock | 0.47%  |
|                             | Manure going to AD                   | Digester - total          | 7.2%   |
| Mature Non-Dairy Cattle     | Slurry<br>Deep litter & solid manure | Liquid system             | 12.18% |
|                             |                                      | Solid storage and dry lot | 10.23% |
|                             | Pasture                              | Pasture range and paddock | 0.47%  |
|                             | Manure going to AD                   | Digester- total           | 7.2%   |
| Young Cattle/Growing cattle | Slurry<br>Deep litter & solid manure | Liquid system             | 12.2%  |
|                             |                                      | Solid storage and dry lot | 10.1%  |
|                             | Pasture                              | Pasture range and paddock | 0.47%  |
|                             | Manure going to AD                   | Digester -total           | 7.2%   |
| Sheep                       | Slurry<br>Deep litter & solid manure | Liquid system             | 12.59% |
|                             |                                      | Solid storage and dry lot | 10.35% |
|                             | Pasture                              | Pasture range and paddock | 0.47%  |
|                             | Manure going to AD                   | Digester -total           | 0.0%   |
| Goats                       | Slurry<br>Deep litter & solid manure | Liquid system             | 13.33% |
|                             |                                      | Solid storage and dry lot | 11.13% |
|                             | Pasture                              | Pasture range and paddock | 0.47%  |
|                             | Manure going to AD                   | Digester -total           | 0.0%   |

<sup>24</sup> 40% abatement for storage tank with tight cover / floating plastic cover / natural crust / animal pit below animal confinement with solid floor, 0% abatement for no cover / animal pit below animal confinement with slatted floor (except for swine manure, which won't form natural crust even if covered, and for poultry, for which a separate MCF factor based on IPCC (2006) is used)

|                                    |                                      |                           |        |
|------------------------------------|--------------------------------------|---------------------------|--------|
| Horses                             | Slurry<br>Deep litter & solid manure | Liquid system             | 10.87% |
|                                    |                                      | Solid storage and dry lot | 4.0%   |
|                                    | Pasture                              | Pasture range and paddock | 0.47%  |
|                                    | Manure going to AD                   | Digester -total           | 0.0%   |
| Swine                              | Slurry<br>Deep litter & solid manure | Liquid system             | 14.12% |
|                                    |                                      | Solid storage and dry lot | 8.62%  |
|                                    | Pasture                              | Pasture range and paddock | NA     |
|                                    | Manure going to AD                   | Digester – total          | 6.82%  |
| Poultry                            | Slurry<br>Deep litter & solid manure | Liquid system             | 1.5%   |
|                                    |                                      | Solid storage and dry lot | 1.5%   |
|                                    | Pasture                              | Pasture range and paddock | NA     |
|                                    | Manure going to AD                   | Digester - total          | 0.0%   |
| Deer                               | Slurry<br>Deep litter & solid manure | Liquid system             | 9.0%   |
|                                    |                                      | Solid storage and dry lot | 2.8%   |
|                                    | Pasture                              | Pasture range and paddock | 0.5%   |
|                                    | Manure going to AD                   | Digester - total          | 0.0%   |
| Reindeer                           | Slurry<br>Deep litter & solid manure | Liquid system             | 9.0%   |
|                                    |                                      | Solid storage and dry lot | 2.8%   |
|                                    | Pasture                              | Pasture range and paddock | 0.5%   |
|                                    | Manure going to AD                   | Digester -total           | 0.0%   |
| Fur farming                        | Slurry<br>Deep litter & solid manure | Liquid system             | 9.0%   |
|                                    |                                      | Solid storage and dry lot | 2.83%  |
|                                    | Pasture                              | Pasture range and paddock | NA     |
|                                    | Manure going to AD                   | Digester -total           | 0.0%   |
| Other animals (ostrich,<br>alpaca) | Slurry<br>Deep litter & solid manure | Liquid system             | 9.0%   |
|                                    |                                      | Solid storage and dry lot | 4.0%   |
|                                    | Pasture                              | Pasture range and paddock | NA     |
|                                    | Manure going to AD                   | Digester - total          | 0.0%   |

Emissions from grazing have been estimated as a separate MMS category for all animal categories to take into account analysis from (Yanjiang Cai et al. 2017) that indicates that there was no significant difference in emission values for different animal categories regardless of the method of representing methane emissions or the climate zone. Thus, a single set of  $B_0$  and MCF factors has been applied to all animal categories, and the default IPCC factor for pasture/Range/Paddock from IPCC (2019) are used for MCF. This factor has

been used over the default factor from the 2006 IPCC Guidelines due to it being based on more recent data and research, and is therefore expected to reflect emissions from grazing more accurately.

#### 5.3.1.1.2 N<sub>2</sub>O

In Norway, all animal excreta that are not deposited during grazing are managed as manure. N<sub>2</sub>O emissions from manure are estimated in a revised nitrogen model which closely follows the stepwise approach proposed in the EMEP/EEA 2019 guidelines (EEA 2019). As the model is based on the nitrogen mass balance approach specified by EMEP/EEA, it allows estimates to be made of all the main nitrogen species, namely NH<sub>3</sub>, NO and N<sub>2</sub> in addition to N<sub>2</sub>O. The estimations are made in accordance with the IPCC tier 2 method (IPCC 2006), using Norwegian values for N in excreta from different animals according to [Table 5.14](#) and Annex VIII, section 3. The rationale for the Norwegian values for N in excreta is provided in Karlengen (2012). For beef cow, the nitrogen excretion factors were estimated by the Norwegian University of Life Sciences (NMBU) in 2018 based on national feeding data for beef cow (Wetlesen et al 2018). The method is described more in detail in Aspehølen Åby et al. (2018) (published in NIR 2019, Annex IX, section 3.2.2). The N-excretion factors for cattle, poultry and pigs have been scientifically investigated, while the remaining categories have been given by expert judgements (Karlengen et al. 2012). Based on typical Norwegian feedstock ratios, the excretion of nitrogen (N) was calculated by subtracting N in growth and products from assimilated N. Comparisons have also been made with emission factors used in other Nordic countries and IPCC default factors.

The factors for cattle are based on equations using animal weight, production (milking cows), lifetime (young cattle) and protein content in the fodder as activity data. The equations for calculating the factors were evaluated by scientist at Norwegian University of Life Sciences in 2022 (Volden 2022).

The Nordic feed evaluation system (NorFor) was used to develop the nitrogen factors for dairy cows and young cattle. Excretions of N in the manure were calculated as the difference between their intake, and the sum of what is excreted in milk, fetus and deposited in the animal itself. The procedure used for calculating the excretion of faeces and N consisted of two steps:

- Simulations in "NorFor" were conducted to gain values for the faeces/manure characteristics covering a wide variation of feed characteristics (N content) and production intensities (milk yield/meat production)

- The results from the simulations were used to develop regression equations between faeces/manure characteristics and parameters related to the diet (N content) and animal characteristics (milk yield, weight, age etc).

Calculations of N-factors based on these equations have been made for all years back to 1990 for cattle. For beef cattle we only have national feeding data from one year. There have been some changes in the composition of the breed of beef cow population in Norway since 1990. But we lack data for a good variable that we could use to get a trend for beef cow. It is expected that this is a minor source of error since the population of beef cow was of less significance earlier. Since the change in the composition of the population has been an increase of heavier breed, this can mean that there is an overestimation of the emissions for the earlier years. For poultry and pigs, N-factors have been estimated for 2011 in Karlengen et al. (2012). The factors used until this update were estimated in 1988 (Sundstøl & Mroz 1988), and are regarded as still valid for 1990. A linear interpolation has been used for the years between 1990 and 2011. For the remaining animal categories, N in excreta is considered constant throughout the time series. More background data for the calculations is provided in Annex VIII, Section 3.1. The factors are shown in [Table 5.14](#). The factors for total N excreted are used in the estimations of N<sub>2</sub>O emissions, whilst ammonium N is used in the estimations of NH<sub>3</sub> and NO<sub>x</sub> emissions. N<sub>2</sub>O emissions from MMS are estimated based on total N excreted, while all other N emissions from MMS are estimated based on N available prior a specific MMS stage.

Norwegian values are also used for the fraction of total excretion per species for each management system (MS) and for pasture. The fractions are updated every year and are provided in [Table 5.15](#) and [Table 5.17](#). This is described in section 5.3.1.2.

**Table 5.14 N in excreta from different animal categories<sup>1</sup>. 2021. kg/animal/year unless otherwise informed in footnote.**

|                                            | Total N | Ammonium N (TAN) |
|--------------------------------------------|---------|------------------|
| Dairy cattle                               | 134.1   | 76.5             |
| Beef cows                                  | 93.0    | 52.6             |
| Replacement heifers <sup>2</sup>           | 93.9    | 58.7             |
| Heifers for slaughter <sup>2</sup>         | 65.7    | 39.8             |
| Bull for slaughter <sup>2</sup>            | 75.0    | 45.7             |
| Sows                                       | 24.4    | 15.3             |
| Boars                                      | 24.4    | 15.3             |
| Piglets                                    | 1.4     | 0.9              |
| Fattening pigs <sup>3</sup>                | 3.2     | 2.1              |
| Young pigs for breeding                    | 9.7     | 6.5              |
| Laying hens                                | 0.7     | 0.3              |
| Chickens reared for laying <sup>3</sup>    | 0.05    | 0.02             |
| Broilers <sup>3</sup>                      | 0.03    | 0.01             |
| Turkeys for slaughter <sup>3</sup>         | 0.5     | 0.2              |
| Ducks and geese for slaughter <sup>3</sup> | 0.1     | 0.03             |
| Turkeys, ducks and geese reared for laying | 2.0     | 0.8              |
| Horses                                     | 50.0    | 25.0             |
| Dairy goats                                | 16.9    | 10.1             |
| Other goats                                | 8.5     | 5.1              |
| Sheep over 1 year old                      | 11.6    | 6.4              |
| Sheep under 1 year old                     | 7.7     | 4.3              |
| Mink                                       | 4.3     | 1.7              |
| Foxes                                      | 9.0     | 3.6              |
| Deer                                       | 12.0    | 5.4              |
| Reindeer                                   | 6.0     | 2.7              |

Source: Karlengen et al. (2012), Aspehølen Åby et al. (2018), Volden (2022) and estimations by Statistics Norway.

<sup>1</sup> Includes pasture.

<sup>2</sup> Factors for excreted nitrogen apply for the whole lifetime of animals, and nitrogen is calculated when animals are slaughtered/replaced.

<sup>3</sup> Per animal. For these categories, lifetime is less than a year. This means that the number of animals bred in a year is higher than the number of stalls (pens).



### 5.3.1.1.3 $\text{NH}_3$

Ammonia volatilized from manure storage represents, together with  $\text{NO}_x$ , the activity data in the estimations of indirect  $\text{N}_2\text{O}$  emissions from atmospheric deposition, source 3Bb5 (atmospheric deposition from manure storage). A model based on the stepwise approach proposed by the EEA (2019) is used for calculating the emissions of ammonia from manure management. The principle of the model is illustrated in Figure 5.3.

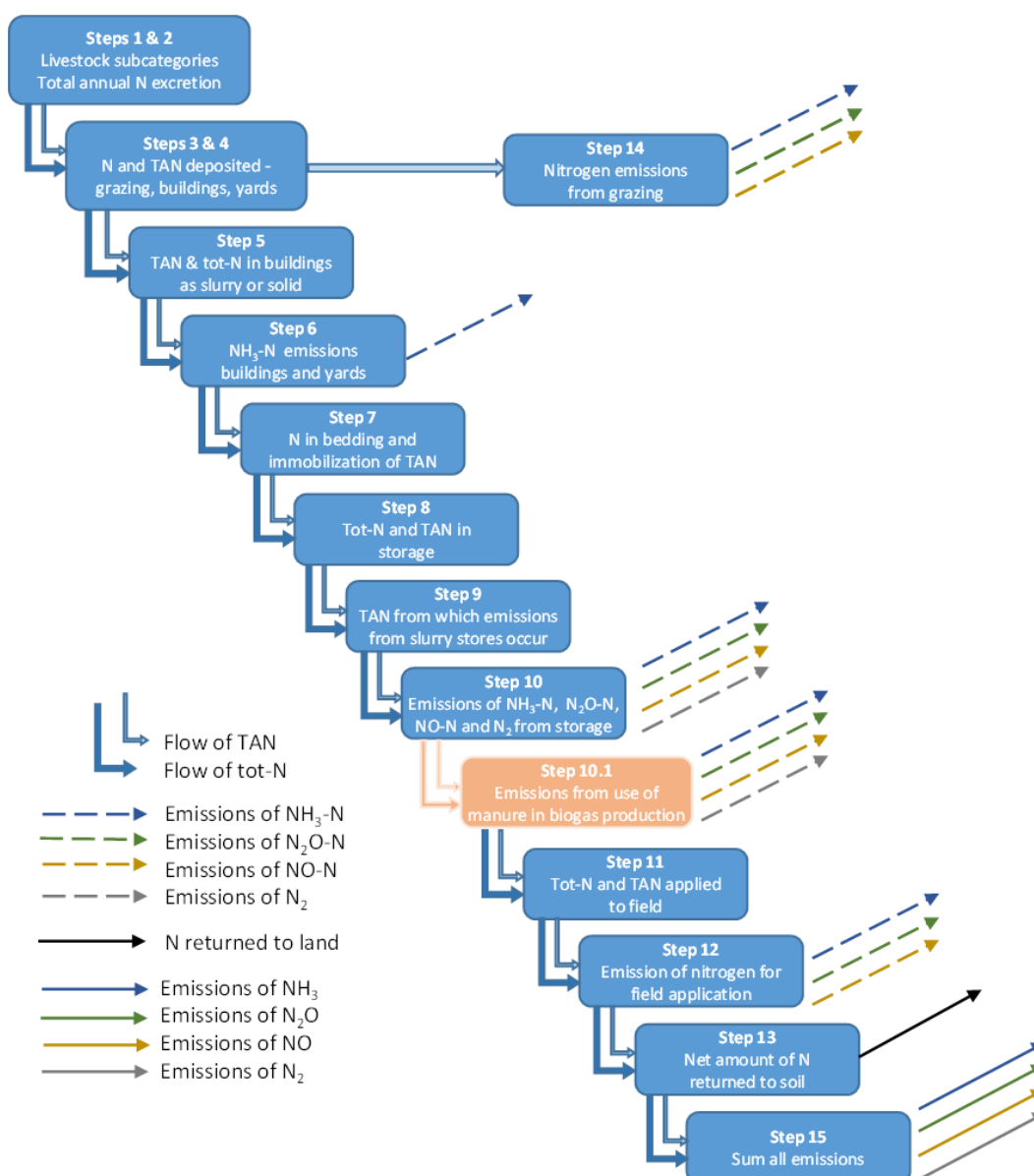


Figure 5-3 The principle of the revised nitrogen model

The revised nitrogen model closely follows the stepwise approach proposed by the EEA (2019) guidelines, with all the 15 steps proposed in the former being followed in the Norwegian model. Emissions of  $\text{NH}_3$  are determined from buildings and yards and from manure storage systems. Total  $\text{NH}_3$  emissions from manure management are estimated by multiplying the amount of manure nitrogen (ammonium N) by the different emission factors for the housing and storage systems, taking into account the effect of any abatement measures and improved practices. In addition, the nitrogen added in bedding (applicable only to solid manure) is taken into account, and the consequent immobilization of TAN in that bedding, in line with EEA (2019). The volumes of different bedding types used is based on Luostarinen et al. (2017). These volumes are converted into weights and thence tot-N added due to bedding as quoted in Grönroos et al. (2017).

Finally, the model accounts for  $\text{NH}_3$  emissions from anaerobic digestion (AD), namely emissions from pre-storage of manure used for AD, emissions from the digester, separation, and storage of digestate. The nitrogen in digestate produced from manure is then assumed to return to land, together with the nitrogen in untreated manure. The amount of ammonium nitrogen in the manure is estimated by the number of animals and ammonium nitrogen excretion factors for each type of animal (see [Table 5.14](#)).

#### 5.3.1.1.4 $\text{NO}_x$

Nitrous oxide volatilized from manure storage represents, together with  $\text{NH}_3$ , the activity data in estimations of indirect  $\text{N}_2\text{O}$  emissions from atmospheric deposition, source 3Bb5 (atmospheric deposition from manure storage).

$\text{NO}_x$  emissions from manure management systems are estimated according to the methodology in EEA (2019). In Norway, all animal excreta that are not deposited during grazing are managed as manure. Norwegian values for N in excreta from different animals according to [Table 5.14](#) are used. Norwegian values are also used for the fraction of total excretion per species for each management system (MS) and for pasture, see [Table 5.16](#) and [Table 5.17](#). The fractions are updated every year.

#### 5.3.1.1.5 Indirect $\text{N}_2\text{O}$ from manure management, 3Bb5

Deposition of nitrogen from manure management is assumed to correspond to the amount of nitrogen in the  $\text{NH}_3$  and  $\text{NO}_x$  that volatilises from manure storage systems (including anaerobic digestion). The  $\text{N}_2\text{O}$  emissions are calculated by multiplying the amount of N from deposition with the IPCC default emission factor of 0.01 kg  $\text{N}_2\text{O-N}/(\text{kg } \text{NH}_3\text{-N} + \text{NO}_x\text{-N volatilized})$  (IPCC 2006).

Storage systems that are not watertight may cause leaching of manure nitrogen. It is assumed that leaching occurs from the storage systems solid storage (not including dry manure in manure cellars), cattle and swine deep bedding, dry lot, and poultry manure. The fractions that are assumed leached are based on expert judgement, see [Table 5.15](#).

| <b>Table 5.15 FracLeach for storage systems that are assumed to have leaching.</b> |                           |
|------------------------------------------------------------------------------------|---------------------------|
|                                                                                    | Frac <sub>Leach</sub> , % |
| Solid storage <sup>1</sup>                                                         | 25                        |
| Cattle and swine deep bedding                                                      | 15                        |
| Dry lot                                                                            | 25                        |
| Poultry manure                                                                     | 25                        |

Source: Expert judgement by Statistics Norway and the Norwegian Agricultural Agency<sup>25</sup>.

<sup>1</sup> Solid manure stored in manure cellars are not assumed to have leaching.

The IPCC default emission factor of 0.0075 kg N<sub>2</sub>O-N/kg N lost to leaching/runoff is used (IPCC 2006).

### 5.3.1.2 Activity data

#### 5.3.1.2.1 CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub> and NH<sub>3</sub>

Emissions are estimated from the animal population. How the animal population is estimated is described in Section 5.1.1 and Annex VIII.

Surveys for assessing use of manure management systems (MMS) have been carried out in 2000, 2003, 2013, 2018 and 2020.

In addition to collecting data on the MMS, the surveys aim to determine the fraction of manure from each animal category that is deposited in pastures as opposed to in animal housing, which is summarized in [Table 5.16](#).

Norway has in 2018 developed a single model for estimating N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub> emissions, which replaces two separate calculation models which were used for previous years. The previous models treated the basic data from the 2013 Manure Survey differently for estimating NH<sub>3</sub> emissions compared to N<sub>2</sub>O and NO<sub>x</sub> emissions due to different manure storage categories being used. For the development of a single model, manure quantities

<sup>25</sup> Email from Jon Magnar Hagen, the Norwegian Agricultural Agency, 25.11.2015.

used in the previous N<sub>2</sub>O model have had to be reassigned between different types of manure storage systems, in addition to re-categorization of manure types between slurry, FYM and solid manure. The fraction of total excretion per animal category for each management system for 2020 onwards is based on Statistics Norway's Census of agriculture for 2020 (Statistics Norway 2021) and presented in [Table 5.17](#).

**Table 5.16 Percent of total excretion per species processed by a MMS (i.e. deposited in housing) and deposited on pasture. 2021.**

|               | % manure to pasture | % manure to MMS |
|---------------|---------------------|-----------------|
| Dairy cattle  | 16%                 | 84%             |
| Beef cows     | 37%                 | 63%             |
| Young cattle  | 24%                 | 76%             |
| Swine         | 0%                  | 100%            |
| Laying hens   | 0%                  | 100%            |
| Broilers      | 0%                  | 100%            |
| Turkeys       | 0%                  | 100%            |
| Other poultry | 0%                  | 100%            |
| Horses        | 26%                 | 74%             |
| Goats         | 30%                 | 70%             |
| Sheep         | 77%                 | 23%             |
| Fur animals   | 0%                  | 100%            |
| Deer          | 100%                | 0%              |
| Reindeer      | 100%                | 0%              |

*Source: Data for storage systems from Statistics Norway (2021), Statistics Norway (Kolle & Oguz-Alper 2020), (Gundersen & Heldal 2015), data for pasture times from (TINE BA Annually) (Dairy cattle, goat), (Statistics Norway 2002).*

**Table 5.17 Fraction of total excretion per animal category for each management system used in the estimations. 2021.**

|                          | In-house slurry pit [pit storage below animal confinements] | Tank without cover [Liquid/slurry] | Tank with cover [Liquid/slurry] | Heaps [solid storage] | In-house deep litter [Cattle and swine deep bedding] | Dry lot |
|--------------------------|-------------------------------------------------------------|------------------------------------|---------------------------------|-----------------------|------------------------------------------------------|---------|
| Dairy cattle             | 0.67                                                        | 0.01                               | 0.32                            | 0.00                  | 0.00                                                 | 0.00    |
| Beef cows                | 0.53                                                        | 0.00                               | 0.16                            | 0.13                  | 0.14                                                 | 0.04    |
| Young cattle             | 0.67                                                        | 0.01                               | 0.23                            | 0.04                  | 0.04                                                 | 0.01    |
| Swine                    | 0.52                                                        | 0.31                               | 0.13                            | 0.02                  | 0.01                                                 | 0.00    |
| Laying hens              | 0.51                                                        | 0.06                               | 0.03                            | 0.36                  | 0.03                                                 | 0.01    |
| Broilers                 | 0.16                                                        | 0.02                               | 0.01                            | 0.74                  | 0.04                                                 | 0.04    |
| Turkeys                  | 0.16                                                        | 0.02                               | 0.01                            | 0.74                  | 0.04                                                 | 0.04    |
| Other poultry            | 0.1                                                         | 0.02                               | 0.02                            | 0.74                  | 0.04                                                 | 0.04    |
| Horses                   | 0.20                                                        | 0.01                               | 0.00                            | 0.58                  | 0.07                                                 | 0.14    |
| Goats                    | 0.82                                                        | 0.01                               | 0.0                             | 0.04                  | 0.10                                                 | 0.02    |
| Sheep                    | 0.72                                                        | 0.01                               | 0.01                            | 0.08                  | 0.13                                                 | 0.05    |
| Fur animals <sup>1</sup> | 0.00                                                        | 0.00                               | 1.00                            | 1.00                  | 0.00                                                 | 0.00    |
| Deer                     | NA                                                          | NA                                 | NA                              | NA                    | NA                                                   | NA      |
| Reindeer                 | NA                                                          | NA                                 | NA                              | NA                    | NA                                                   | NA      |

Source: Data for storage systems from Statistics Norway's Census of agriculture 2020.

<sup>1</sup> Based on expert opinion Norwegian Institute of Bioeconomy Research (NIBIO)

Data on storage systems for years other than those covered by the manure survey is not available. Separate estimations of the effects on emissions of the assumed changes in storage systems since 1990 show that these assumed changes do not significantly impact the emissions. For the intermediate years between the surveys of 2003, 2013, 2018 and 2020 the distribution of management system has been estimated using a linear interpolation of changes between 2003 and 2013, between 2014 and 2018 and between 2019 and 2020 for each system. The surveys on management systems do not usually include pasture, but for 2018 manure survey this was included and gave updated pasture data for other cattle and sheep. Data for pasture times for dairy cattle and dairy goat has however been annually updated in the Cow Recording System (TINE BA Annually) until 2013, while for the other animals, data from Sample survey of agriculture and forestry for 2001 at Statistics Norway (2002) is used.

In the CH<sub>4</sub> estimations, the share of the manure stored more respective less than one month in pit storage below animal confinement before spreading is based on expert

judgement<sup>26</sup>. It is assumed that 1/6 of the manure is stored less than 1 month, the rest more than 1 month.

In the manure surveys of 2000, 2013 and 2018 and the Census of agriculture 2020 the manure of each management system is distributed by all combinations of the following regions and productions:

Regions:

- South-Eastern Norway
- Hedmark and Oppland
- Rogaland
- Western Norway
- Trøndelag
- Northern Norway

Production<sup>27</sup>:

- Cattle
- Swine
- Sheep
- Goats and horses
- Poultry

The activity data on the amount of manure used for biogas production data from the Norwegian Agriculture Agency is used (Norwegian Agriculture Agency 2022). The data covers all farmers who are applying for financial support for establishing biogas facilities. Only cattle and swine manure are currently used for anaerobic digestion in Norway (2021). The figures are very modest, representing about 1 – 1.5% of the total volatile solids in all manure deposited in housing.

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<sup>26</sup> Personal communication John Morken, NMBU, 6.8.2014

<sup>27</sup> The grouping of animals is different in the two surveys. Cattle is one category in the 2000 survey and three categories in the 2013 survey. Goats are grouped with sheep in the 2000 survey, but with horses in the 2013 survey. Horses are grouped with other animals in the 2000 survey. Fur bearing animals are not included in the 2013 survey

### **5.3.1.3 Emission factors**

#### **5.3.1.3.1 CH<sub>4</sub>**

Country specific tier 2 emission factors are used for all animal categories as described in section 5.3.1.1.

#### **5.3.1.3.2 N<sub>2</sub>O**

The IPCC default values for N<sub>2</sub>O emission factors from manure management from the 2006 IPCC Guidelines (IPCC 2006) are used and applied to total N excreted. In addition, some changes based on recommendations in Rivedal et al. (2019) are implemented to the N<sub>2</sub>O emission factors for manure cellar with slatted floors, and manure tank with floating cover (natural crust) to better reflect national circumstances. The factors used in the inventory are given in [Table 5.18](#). A more detailed description of the emission factors used is given in Carbon Limits (2020a).

**Table 5.18 Emission factors for direct N<sub>2</sub>O emissions from manure management per manure management system, kg N<sub>2</sub>O-N/kg N excreted.**

|                                                                      | Manure cellar for slurry, under slatted floor                                                                | Manure cellar for slurry, under solid floor                                                                             | Open manure tank for slurry                  | Manure tank with tight roof               | Manure tank, floating cover (plastic, lecca) | Manure tank, floating cover (natural crust) | Indoor built up/deep litter   | Outdoors built up/deep litter | Solid manure, outdoor storage |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-------------------------------------------|----------------------------------------------|---------------------------------------------|-------------------------------|-------------------------------|-------------------------------|
| System as described in IPCC 2006 (all categories other than poultry) | For sheep, horses, goats - pit storage below animal confinements, for others - liquid / slurry without cover | For sheep, horses, goats - pit storage below animal confinements, for others - liquid / slurry with natural crust cover | Liquid / slurry, without natural crust cover | Liquid / slurry, with natural crust cover | Liquid / slurry, with natural crust cover    | Liquid / slurry, with natural crust cover   | cattle and swine deep bedding | dry lot                       | solid storage                 |
| Dairy cattle                                                         | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Beef cow                                                             | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Young cattle                                                         | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Swine                                                                | 0.0025                                                                                                       | 0.0005                                                                                                                  | -                                            | 0.0005                                    | 0.0005                                       | 0.0003                                      | 0.01                          | 0.02                          | 0.005                         |
| Laying hens                                                          | 0.001                                                                                                        | 0.001                                                                                                                   | 0.001                                        | 0.001                                     | 0.001                                        | 0.0010                                      | 0.001                         | 0.001                         | 0.001                         |
| Broilers                                                             | 0.001                                                                                                        | 0.001                                                                                                                   | 0.001                                        | 0.001                                     | 0.001                                        | 0.0010                                      | 0.001                         | 0.001                         | 0.001                         |
| Turkeys                                                              | 0.001                                                                                                        | 0.001                                                                                                                   | 0.001                                        | 0.001                                     | 0.001                                        | 0.001                                       | 0.001                         | 0.001                         | 0.001                         |
| Other poultry                                                        | 0.001                                                                                                        | 0.001                                                                                                                   | 0.001                                        | 0.001                                     | 0.001                                        | 0.001                                       | 0.001                         | 0.001                         | 0.001                         |
| Horses                                                               | 0.002                                                                                                        | 0.002                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Goats                                                                | 0.002                                                                                                        | 0.002                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Sheep                                                                | 0.002                                                                                                        | 0.002                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Fur animals                                                          | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Deer                                                                 | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Reindeer                                                             | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |
| Dairy cattle                                                         | 0.0025                                                                                                       | 0.005                                                                                                                   | -                                            | 0.005                                     | 0.005                                        | 0.0025                                      | 0.01                          | 0.02                          | 0.005                         |



|              |        |        |       |        |        |        |       |       |       |
|--------------|--------|--------|-------|--------|--------|--------|-------|-------|-------|
| Beef cow     | 0.0025 | 0.005  | -     | 0.005  | 0.005  | 0.0025 | 0.01  | 0.02  | 0.005 |
| Young cattle | 0.0025 | 0.005  | -     | 0.005  | 0.005  | 0.0025 | 0.01  | 0.02  | 0.005 |
| Swine        | 0.0025 | 0.0005 | -     | 0.0005 | 0.0005 | 0.0003 | 0.01  | 0.02  | 0.005 |
| Laying hens  | 0.001  | 0.001  | 0.001 | 0.001  | 0.001  | 0.0010 | 0.001 | 0.001 | 0.001 |

Source: IPCC (2006) and Rivedal et al. (2019)

#### 5.3.1.3.3 NH<sub>3</sub>

Emission factors vary with production and storage system; in the model there is no variation between regions for the manure management systems. The factors used are shown in Table 5.19. All emission factors in Table 5.19 are sourced from EEA (2019), since measurements of NH<sub>3</sub> losses in animal housing and manure storage have so far not been carried out in Norway.

**Table 5.19 NH<sub>3</sub> emissions factors for various storage systems and productions. % losses of N of ammonium N.**

|               | Housing |              | Storage |       |
|---------------|---------|--------------|---------|-------|
|               | Slurry  | Solid manure | Slurry  | Solid |
| Dairy cattle  | 24%     | 8%           | 25%     | 32%   |
| Suckling cows | 24%     | 8%           | 25%     | 32%   |
| Young cattle  | 24%     | 8%           | 25%     | 32%   |
| Swine         | 27%     | 23%          | 11%     | 29%   |
| Laying hens   | 41%     | 20%          | 14%     | 8%    |
| Broilers      | 21%     | 21%          | 30%     | 30%   |
| Turkeys       | 35%     | 35%          | 24%     | 24%   |
| Other poultry | 57%     | 57%          | 24%     | 24%   |
| Horses        | 22%     | 22%          | 35%     | 35%   |
| Goats         | 22%     | 22%          | 28%     | 28%   |
| Sheep         | 22%     | 22%          | 32%     | 32%   |
| Fur animals   | 27%     | 27%          | 9%      | 9%    |
| Deer          | 24%     | 24%          | 25%     | 25%   |

Source: EMEP/EEA air pollutant emission inventory Guidebook 2019: 3.B Manure management (EEA 2019)

As recommended in EEA (2019), the effect of the abatement measures and improved practices are described using a reduction factor, i.e., a proportional reduction in the emission estimate for the unabated situation. These reduction factors are summarized in Table 5.20.

**Table 5.20 NH<sub>3</sub> abatement measures for manure management systems and corresponding emission reduction, % applied to NH<sub>3</sub> emissions factors presented in Table 5.19**

|                                      | Housing                                  |                                        | Storage                      |                                                    |               |                                 |
|--------------------------------------|------------------------------------------|----------------------------------------|------------------------------|----------------------------------------------------|---------------|---------------------------------|
| Abatement measure                    | In-house slurry pit, below slatted floor | In-house slurry pit, below solid floor | Tank with cover, "tight" lid | Tank with cover, plastic sheeting (floating cover) | Natural crust | "Low technology" floating cover |
| NH <sub>3</sub> emission reduction,% | 30                                       | 60                                     | 80                           | 60                                                 | 40            | 40                              |
| NH <sub>3</sub> emission reduction,% | 30                                       | 60                                     | 80                           | 60                                                 | 40            | 40                              |

Source: Rösemann et al. (2017), UNECE (2014), Rivedal et al. (2019).

To estimate losses, these unabated or amended emission factors are in turn multiplied with the amount of manure (based on number of animals and N-factors per animal) entering each of the different housing or storage category, as determined by the Statistics Norway survey of different storage systems in 2000 (Gundersen & Rognstad 2001), the Sample survey of agriculture and forestry 2003 (Statistics Norway 2004), data from the report *Use of inorganic and organic fertilizers in agriculture 2013* (Gundersen & Heldal 2015), Statistics Norway 2018 survey on manure management systems (Kolle & Oguz-Alper 2020) and Census of agriculture 2020 (Statistics Norway 2021). The changes in storage systems from 2003 to 2013, 2013 to 2018 and between 2019 and 2020 have been linearly interpolated in the intermediate years. From 1990-2002 and from 2020, the number of animals is the only activity data that differs from year to year.

#### 5.3.1.3.4 NO<sub>x</sub>

The emissions factors used for NO<sub>x</sub> emissions in manure management systems are shown in Table 5.21.

| <b>Table 5.21 NO<sub>x</sub> and N<sub>2</sub> emission factors for manure management per manure management system.</b> |                                            |
|-------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
|                                                                                                                         | kg of N in NO or N <sub>2</sub> (kg TAN)-1 |
| NO <sub>x</sub> Slurry storage                                                                                          | 0.0001                                     |
| N <sub>2</sub> Slurry storage                                                                                           | 0.0030                                     |
| NO <sub>x</sub> Solid storage                                                                                           | 0.01                                       |
| N <sub>2</sub> Solid storage                                                                                            | 0.30                                       |

Source: EEA (2019)

N excretions is estimated as total ammoniacal nitrogen (TAN), which is the same N excretion factor that is used in the estimations of NH<sub>3</sub> from manure management systems. For estimating N<sub>2</sub> from storage the amount is estimated as ammonia-N (TAN) and the default values for the EFs given in EEA (2019) (table 5.7) are used.

### 5.3.2 Uncertainties and time-series consistency

Uncertainties estimates are provided in Annex II.

#### 5.3.2.1 Activity data

##### 5.3.2.1.1 CH<sub>4</sub>

The data for the number of animals is considered to be known within  $\pm 5\%$ . Other activity data are the different kinds of manure treatment (which will determine the emission factor), which have been assessed by expert judgments. This will contribute to the uncertainty.

##### 5.3.2.1.2 N<sub>2</sub>O and NH<sub>3</sub>

The data for the number of animals is considered to be known within  $\pm 5\%$ .

For the emissions from manure management, Norwegian data for N in excreta is used (Table 5.14). The nitrogen excretion factors are uncertain, but the range is considered to be within  $\pm 15\%$  (Rypdal 1999). The uncertainty has not been estimated for the revised nitrogen excretion factors from Karlengen et al (2012), and in the key category analysis is the uncertainty estimate for the country specific nitrogen excretion factors from 1999 still used as the best available estimate. This can be considered as a conservative estimate of the uncertainty since it is expected that the new nitrogen excretion factors have a lower uncertainty. The uncertainty is connected to differences in excretion between farms in different parts of the country, the fact that the survey farms may not have been representative, general measurement uncertainty and the fact that fodder and fodder practices have changed since the factors were determined.

There is also an uncertainty connected to the division between different storage systems for manure, which is considered to be within  $\pm 10\%$ , and the division between storage and pasture, which is considered to be within  $\pm 15\%$ .

### **5.3.2.2 Emission factors**

#### **5.3.2.2.1 CH<sub>4</sub>**

The emission factors, based on Tier 2 for all animal categories, are considered to have the uncertainty range  $\pm 20\%$ .

#### **5.3.2.2.2 N<sub>2</sub>O**

For the emission of N<sub>2</sub>O from different storage systems, IPCC default emission factors are used. They have an uncertainty range of a factor of 2 (IPCC 2006).

#### **5.3.2.2.3 NH<sub>3</sub>**

All emission factors for NH<sub>3</sub> which have been used for both housing and storage are sourced from EEA (2019). As stated in EEA (2019), uncertainties with regard to NH<sub>3</sub> EFs vary considerably. EEA (2019) concludes that the overall uncertainty for the United Kingdom NH<sub>3</sub> emissions inventory, as calculated using a Tier 3 approach, was  $\pm 21\%$  (Webb and Misselbrook, 2004), while that for the Netherlands, also calculated using a Tier 3 approach, was  $\pm 25\%$ .

#### **5.3.2.2.4 NO<sub>x</sub>**

Uncertainty has not been assessed. According to EEA (2019), uncertainty is high, ranging between -50% to + 100%.

### **5.3.3 Category specific QA/QC and verification**

In 2011, the Norwegian University of Life Sciences (NMBU) published a comparison of the methodologies used for calculating CH<sub>4</sub> emissions from manure management in Sweden, Finland, Denmark and Norway (Morken & Hoem 2011).

In a project in 2012 at the Norwegian University of Life Sciences (NMBU) that updated the Norwegian nitrogen excretion factors and the values for manure excreted for the different animal species, comparisons were made with the corresponding factors used in Sweden, Denmark and Finland and with IPCC default factors as a verification of the Norwegian factors (Karlengen et al. 2012).

A project with the aim to revise the Norwegian CH<sub>4</sub> conversion factors (MCF) for the manure storage systems in use was conducted at the Norwegian University of Life Sciences

(NMBU) in 2013. The maximum CH<sub>4</sub> producing capacity (B<sub>0</sub>) was also revised for cattle manure.

The methodology for estimating methane from manure management was revised in the 2014 submission. The emissions of methane from manure for cattle, pigs and poultry were estimated with tier 2 method in accordance with IPCC GPG (IPCC 2000). The population of animals was brought into consistency with the animal data used elsewhere in the inventory.

In 2014, a new manure survey for 2013 was carried out by Statistics Norway (Gundersen & Heldal 2015). The results are implemented in the estimations of CH<sub>4</sub> and N<sub>2</sub>O emissions from manure. Statistics Norway's detailed manure survey gave more extended activity data, which is better related to emission source categories, for manure management and spreading.

In 2018, the model for calculating emissions of N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub> from manure was revised. As part of the revision of the nitrogen model undertaken in 2018, a review was undertaken of the Norwegian emissions factors compared to those used in other Nordic and Northern European countries. The review demonstrated that the Norwegian EFs compare well with those used in other Nordic and Northern European countries. In most cases the EFs used in the Norwegian model lie within the range of EFs used by the example countries, and in most cases are at the upper end of the range which demonstrates the conservative approach taken in the absence of country specific EFs. For more information about the comparison of Norwegian EF values with those used in other countries, see chapter 2.6 of Carbon Limits (2018).

In 2019, the model for calculation of CH<sub>4</sub> from manure was revised, taking into account the amount of manure that enters biogas facilities.

In 2021 the Nex and VS factors for cattle were evaluated by the Norwegian University of Life Sciences (Volden 2022). This led to updated VS factor for dairy cattle. The evaluation of the Nex factors on the other hand, showed a high correlation with recent experimental data, both for dairy cattle and growing cattle.

In 2022, the VS factors for young cattle were updated as a result of the same 2021 project (Volden 2022). This resulted in 3 per cent higher CH<sub>4</sub> emissions through the timeseries as an average. More detailed information is presented in chapter 10, Recalculations.

### 5.3.4 Category-specific recalculations

Animal population:

As a result of updated information, the sheep population numbers were revised for 2020. The updated numbers were estimated 2% higher for both sheep > one year and sheep < one year.

| 2020- animal number | 2022 submission | 2023 submission |
|---------------------|-----------------|-----------------|
| sheep > one year    | 630 392         | 644 880         |
| sheep < one year    | 649 029         | 660 826         |

The activity data on manure management system and spreading for 2019 and 2020 was updated with data from the Statistics Norway's Census of agriculture 2020. This only led to small changes in the manure housing and storage distribution. For emissions from spreading the changes were also small but led to a recalculation in the whole time series due to harmonization of data. This is fully described in chapter 10, recalculations.

For CH<sub>4</sub> estimations the updated VS factors for young cattle led to 3% higher CH<sub>4</sub> emissions from 3B on average from 1990 to 2020 in the 2023 submission compared to the previous submission. The changes are explained in more detail in chapter 10.

For indirect N<sub>2</sub>O emissions from manure management the time series was recalculated. An error correction in TAN factor for the animal category "heifers for breeding" gave higher updated values for NH<sub>3</sub> and NO<sub>x</sub>.

Since NH<sub>3</sub> and NO<sub>x</sub> emissions are basis for indirect N<sub>2</sub>O emissions this resulted in 1.4 per cent higher N<sub>2</sub>O emissions as an average through the time series compared to previous submission.

### 5.3.5 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 5.4 Direct and indirect N<sub>2</sub>O emissions from agricultural soils - 3D (Key categories for N<sub>2</sub>O)

### 5.4.1 Category description

The emissions of N<sub>2</sub>O from agricultural soils in Norway in 2021 amounted to 1.5 Mtonnes calculated in CO<sub>2</sub> equivalents. They accounted for about 31% of the total Norwegian GHG emissions from agriculture in 2021.

The emissions had minor fluctuations in the period 1990-2021. During the period 1990-2021, emissions increased by 0.4%. From 2020 to 2021, the emissions increased by 1.0%.

**Table 5.22 Emission trends for 3D Direct and indirect N<sub>2</sub>O emissions from agricultural soils (kt CO<sub>2</sub> equivalents).**

| Source category                                                                              | 1990  | 1990, % of Agriculture | 2020  | 2021  | 2021, % of Agriculture | Trend 1990-2021 (%) | Trend 2020-2021 (%) |
|----------------------------------------------------------------------------------------------|-------|------------------------|-------|-------|------------------------|---------------------|---------------------|
| 3Da1. Inorganic N fertilizers                                                                | 459   | 9 %                    | 441   | 447   | 10 %                   | -3 %                | 1 %                 |
| 3Da2. Organic N fertilizers                                                                  | 209   | 4 %                    | 243   | 246   | 5 %                    | 18 %                | 1 %                 |
| 3Da3. Urine and dung deposited by grazing animals                                            | 173   | 3 %                    | 155   | 159   | 3 %                    | -8 %                | 2 %                 |
| 3Da4. Crop residues                                                                          | 93    | 2 %                    | 67    | 66    | 1 %                    | -29 %               | -1 %                |
| 3Da6. Cultivation of organic soils                                                           | 317   | 6 %                    | 342   | 343   | 7 %                    | 8 %                 | 0 %                 |
| 3Db1. Indirect N <sub>2</sub> O Emissions from managed soils - Atmospheric deposition        | 68    | 1 %                    | 65    | 66    | 1 %                    | -3 %                | 2 %                 |
| 3Db2. Indirect N <sub>2</sub> O Emissions from managed soils - Nitrogen leaching and run-off | 143   | 3 %                    | 140   | 142   | 3 %                    | -1 %                | 1 %                 |
| 3D. Total                                                                                    | 1 462 | 30 %                   | 1 453 | 1 468 | 31 %                   | 0 %                 | 1 %                 |

Source: Statistics Norway and Norwegian Environment Agency

Different sources of N<sub>2</sub>O from agricultural soils are distinguished in the IPCC methodology, namely:

- Direct emissions from agricultural soils (from use of synthetic fertilizers, animal excreta nitrogen, sewage sludge and other organic fertilizers applied to soils, droppings from grazing animals, crop residues and cultivation of soils with a high organic content).
- N<sub>2</sub>O emissions indirectly induced by agricultural activities (N losses by volatilization, leaching and run-off).

The use of synthetic fertilizers, animal excreta nitrogen and sewage sludge used as fertilizer, and other organic fertilizers applied to soils also results in emissions of NH<sub>3</sub> and NO<sub>x</sub> that gives indirect N<sub>2</sub>O emissions from volatilization. NH<sub>3</sub> volatilized from grazing animals are also included in the estimations of indirect N<sub>2</sub>O.

Section 5.1.2 gives more information about nitrogen in animal manure as basis for emission estimates and an overview of the manure nitrogen flows in the Norwegian greenhouse gas inventory.

Emissions of N<sub>2</sub>O from agricultural soils are key categories, both in level and trend.

#### **5.4.1.1 Inorganic N fertilizers, 3Da1**

##### 5.4.1.1.1 Methodological issues

###### N<sub>2</sub>O

IPCC Tier 1 methodologies and default emission factors (IPCC 2006) are used for estimating direct N<sub>2</sub>O emissions from managed soils.

The direct emissions of N<sub>2</sub>O from use of synthetic fertilizers are calculated from data on total annual amount of fertilizer sold in Norway and its nitrogen content. Before 2013 these figures are calculated by subtracting the amount of synthetic fertilizer applied in forest. The resulting amount that is applied on agricultural fields is multiplied with the IPCC default emission factor (IPCC 2006).

###### NH<sub>3</sub>

The calculations of NH<sub>3</sub> emissions from the use of synthetic fertilizer are based on the amounts of nitrogen supplied and emission factors for the percentage of nitrogen emitted as NH<sub>3</sub> during spreading.



NO<sub>x</sub>

The nitrogen in synthetic fertilizer applied to soil has been multiplied with the default tier 1 emission factor to estimate the nitric oxide (NO<sub>2</sub>) emission from crop production.

## 5.4.1.1.2 Activity data

N<sub>2</sub>O

The Norwegian Food Safety Authority calculates a total value for annual consumption of synthetic fertilizers in Norway based on sale figures (Norwegian Food Safety Authority Annually). For the data before 2013 the figures are corrected for the amount fertilizer used in forests which is provided yearly by the Norwegian Institute of Bioeconomy Research (NIBIO).

The calculation of emissions from use of nitrogen fertilizer is based on sales figures for each year. A strong price increase for nitrogen fertilizer caused a stock building in 2008 and corresponding lower sales in 2009. In addition, new fertilization standards may have brought about a reduction of the use of fertilizers. To correct for this, a transfer of fertilizer use has been made from 2008 to 2009.

NH<sub>3</sub>

For the calculation of the emission of NH<sub>3</sub>, the amount of total N in the fertilizer is used (the same as for estimating N<sub>2</sub>O). For the calculation of the emission of NH<sub>3</sub>, we need a specification of the use of different types of synthetic fertilizer since the NH<sub>3</sub> emission factor vary between the different types. This is given by the Norwegian Food Safety Authority for the years from 2000. Due to lack of data for the years before 2000, we have to assume that the percentual distribution between the usage of different fertilizer types is the same as in 1994 for these years.

NO<sub>x</sub>

For the calculation of the emission of NO<sub>x</sub>, the amount of total N in the fertilizer is used (the same as for estimating N<sub>2</sub>O).

## 5.4.1.1.3 Emission factors

N<sub>2</sub>O

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg N applied (IPCC 2006) has been used.

NH<sub>3</sub>

The percentage of nitrogen emitted as NH<sub>3</sub> during spreading (frac<sub>gasf</sub>) are used as emission factor. More information about the calculation of frac<sub>gasf</sub> and the NH<sub>3</sub> emission factors (g NH<sub>3</sub>/kg N applied) for the different types of fertilizers is provided in Annex VIII, section 4.

NO<sub>x</sub>

The tier 1 default emission factor of 0.04 kg NO<sub>2</sub>/ kg fertilizer-N applied (EEA 2019) has been used.

**5.4.1.2 Animal manure applied to soils, 3Da2**

## 5.4.1.2.1 Methodological issues

N<sub>2</sub>O

IPCC Tier 1 methodologies and default emission factors (IPCC 2006) are used for estimating direct N<sub>2</sub>O emissions from animal manure applied to managed soils.

In Norway, all animal excreta that are not deposited during grazing are used as manure and applied to soils. Further, it is assumed that animals do not emit N<sub>2</sub>O themselves. NH<sub>3</sub> emissions in housing and storage, and N<sub>2</sub>O emissions in housing and storage and manure application are all estimated individually, and the emission estimates are based on the same nitrogen pool.

The emission of N<sub>2</sub>O from manure used as fertilizer is calculated by multiplying the total amount of N in manure used as fertilizer with the IPCC default emission factor (IPCC 2006). This amount is equivalent to total N excreted from the animals deducted for the amount dropped during grazing.

NH<sub>3</sub>

NH<sub>3</sub> emissions from spreading of manure depend on several factors, e.g., climate and time of spreading of manure, type of cultivation and cultivation practices and characteristics of the soil.

Emissions of ammonia are calculated for spreading of manure on cultivated fields and meadow. The total amount of manure nitrogen that is spread is estimated by the number of animals and nitrogen excretion factors for each type of animal and is thereafter distributed on different spreading methods based on national data. The nitrogen basis for the estimated amounts of nitrogen that volatilises as NH<sub>3</sub> during spreading takes into account the amount of nitrogen in the NH<sub>3</sub>, NO<sub>x</sub>, and N<sub>2</sub> that volatilises during housing and storage, as well as the N lost as N<sub>2</sub>O and leaching during storage. Total emissions from spreading are estimated by emission factors for each different spreading method used multiplied by the amount of manure nitrogen spread with the respective method.

NO<sub>x</sub>

The nitrogen in manure applied to soil has been multiplied with the default tier 1 emission factor to estimate the nitric oxide emissions.

## 5.4.1.2.2 Activity data

N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub>

The amount of N in manure systems is calculated as total N in manure adjusted for the N that is dropped on pastures. Nitrogen in manure which is used for anaerobic digestion and then returned to soil is also included as part of the system.

Emissions of N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub> during spreading are calculated from the amounts of N excreted minus losses due to housing and storage emissions.

There are several sources of activity data on spreading of manure. The main sources are manure surveys performed in 2000, 2013 and 2018 by Statistics Norway (Gundersen & Rognstad 2001), (Gundersen & Heldal 2015), (Kolle & Oguz-Alper 2020) and Statistics Norway (2021), various sample surveys of agriculture and forestry 1990-2007 and the annual animal population.

Data from the manure survey only exists for 2000, 2013, 2018 and 2020, while the data from the sample surveys has been updated for several, but not all, years. The manner of spreading the manure affects the NH<sub>3</sub> emissions estimates, while the N<sub>2</sub>O emission estimations are insensitive to methods of spreading.

How the amount of nitrogen in animal manure is estimated is further described in section 5.1.2 and 5.3.1.1. How the animal population is estimated is described in Section 5.1.1 and Annex VIII.

Nitrogen factor are estimated by Karlengen et al (2012), Aspeholen Åby et al. (2018) and Volden (2022). In the estimations of NH<sub>3</sub> losses, the factors of N excretion correspond to the estimated nitrogen excreted in the urine.

| <b>Table 5.23 Sources for activity data for emissions from animal manure applied to soils</b> |                                                                                                                                                                                                                                                      |
|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                               | Sources                                                                                                                                                                                                                                              |
| Number of animals                                                                             | Statistics Norway (applications for productions subsidies, no. and weight of approved carcasses), The Cow Recording System (TINE BA Annually)                                                                                                        |
| Nitrogen factors for manure, Annex VIII, section 3.                                           | Karlengen et al. (2012), Aspehølen Åby et al. (2018), Volden (2022) various sources, compiled by Statistics Norway                                                                                                                                   |
| Distribution between manure storage systems                                                   | Sample Survey of agriculture and forestry 2003 (Statistics Norway 2004), manure survey in 2000, 2013 and 2018 (Gundersen & Rognstad 2001; Gundersen & Heldal 2015; Kolle & Oguz-Alper 2020) and Census of agriculture 2020 (Statistics Norway 2021). |
| Pasture times for different animal categories                                                 | TINE BA (Annually) (Dairy cows, goat), Statistics Norway's Sample Survey 2001 (Statistics Norway 2002) (non-dairy cattle, sheep), Statistics Norway's manure survey 2018 (Kolle & Oguz-Alper 2020) and expert judgements.                            |

| <b>Table 5.24 Parameters included in the estimation of NH<sub>3</sub> emissions from manure.</b> |                                                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                  | Sources                                                                                                                                                                                                   |
| Area where manure is spread, split on cultivated field and meadow                                | Statistics Norway (Sample Surveys of Agriculture, various years), (Gundersen & Rognstad 2001), (Gundersen & Heldal 2015; Kolle & Oguz-Alper 2020) and Census of agriculture 2020 (Statistics Norway 2021) |
| Area and amount where manure is spread, split on spring and autumn                               | (Gundersen & Rognstad 2001), (Gundersen & Heldal 2015; Kolle & Oguz-Alper 2020)                                                                                                                           |
| Addition of water to manure                                                                      | (Gundersen & Rognstad 2001; Gundersen & Heldal 2015), expert judgements, Statistics Norway's Sample Survey 2006 (Statistics Norway 2007)                                                                  |
| Spreading techniques                                                                             | (Gundersen & Rognstad 2001; Gundersen & Heldal 2015; Kolle & Oguz-Alper 2020), Census of agriculture 2020 (Statistics Norway 2021) and expert judgements                                                  |

#### 5.4.1.2.3 Emission factors

##### N<sub>2</sub>O

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg N applied (IPCC 2006) has been used.

##### NH<sub>3</sub>

Emission factors for spreading of stored manure vary with spreading method, water contents, type, and time of treatment of soil, time of year of spreading cultivation and region.

The basic factors used are shown in Table 5.25.

| <b>Table 5.25 Emissions factors for NH<sub>3</sub>-N for various methods of spreading of manure. % of ammonium N.</b> |             |                    |                              |        |        |
|-----------------------------------------------------------------------------------------------------------------------|-------------|--------------------|------------------------------|--------|--------|
| Meadow                                                                                                                |             |                    | Spring                       | Summer | Autumn |
| Spreading method                                                                                                      | Added water |                    | kg NH <sub>3</sub> -N/kg TAN |        |        |
| Broadcast spreading                                                                                                   | < 100%      |                    | 0.4                          | 0.7    | 0.7    |
|                                                                                                                       | > 100%      |                    | 0.24                         | 0.35   | 0.35   |
| Trailing hose                                                                                                         | < 100%      |                    | 0.3                          | 0.5    | 0.4    |
|                                                                                                                       | > 100%      |                    | 0.18                         | 0.25   | 0.2    |
| Injection                                                                                                             |             |                    | 0.15                         | 0.30   | 0.05   |
| Dry manure                                                                                                            |             |                    | 0.7                          | 0.9    | 0.7    |
| Arable land                                                                                                           |             | Incorporation time | Spring                       | Summer | Autumn |
| Spreading method                                                                                                      | Added water | Hours              | kg NH <sub>3</sub> -N/kg TAN |        |        |
| Broadcast spreading                                                                                                   | < 100%      | 0-1                | 0.08                         | 0.08   | 0.12   |
|                                                                                                                       |             | 1-4                | 0.20                         | 0.20   | 0.30   |
|                                                                                                                       |             | 4-12               | 0.33                         | 0.33   | 0.45   |
|                                                                                                                       |             | 12+                | 0.50                         | 0.50   | 0.45   |
|                                                                                                                       | > 100%      | 0-1                | 0.04                         | 0.04   | 0.06   |
|                                                                                                                       |             | 1-4                | 0.10                         | 0.10   | 0.15   |
|                                                                                                                       |             | 4-12               | 0.17                         | 0.17   | 0.28   |
|                                                                                                                       |             | 12+                | 0.25                         | 0.25   | 0.28   |
| Trailing hose                                                                                                         | < 100%      | 0-1                | 0.03                         | 0.03   | 0.05   |
|                                                                                                                       |             | 1-4                | 0.12                         | 0.12   | 0.17   |
|                                                                                                                       |             | 4-12               | 0.23                         | 0.23   | 0.35   |
|                                                                                                                       |             | 12+                | 0.50                         | 0.50   | 0.45   |
|                                                                                                                       | > 100%      | 0-1                | 0.02                         | 0.02   | 0.02   |
|                                                                                                                       |             | 1-4                | 0.06                         | 0.06   | 0.09   |
|                                                                                                                       |             | 4-12               | 0.12                         | 0.12   | 0.22   |
|                                                                                                                       |             | 12+                | 0.25                         | 0.25   | 0.28   |
| Dry manure                                                                                                            |             |                    | 0.70                         | 0.70   | 0.70   |

Source: Karlsson S. and Rodhe L. (2002), Morken and Nesheim (2004), Rösemann et al. (2017)

The factors in [Table 5.25](#) are combined with data from the Sample survey of agriculture and forestry 2006 (Statistics Norway 2007) and a time series on mixture of water in manure. Emission factors for  $\text{NH}_3$  emissions from spreading of manure are connected to activity data that is updated for the whole time series when new information is available, i.e., number of animals (amount of manure), time of spreading and type of cultivation of the areas where the manure is spread.

#### $\text{NO}_x$

The tier 1 default emission factor of 0.04 kg  $\text{NO}_2$ /kg fertilizer-N applied (EEA 2019) has been used.

### **5.4.1.3 Sewage sludge applied to soils, 3Da2**

#### 5.4.1.3.1 Methodological issues

##### $\text{N}_2\text{O}$

IPCC Tier 1 methodologies and default emission factors (IPCC 2006) are used for estimating direct  $\text{N}_2\text{O}$  emissions from managed soils.

Data for the  $\text{N}_2\text{O}$  emission arising from sewage sludge applied on fields has been calculated by multiplying the amount of nitrate in the sewage sludge applied with the IPCC default emission factor.

##### $\text{NH}_3$

The calculation of  $\text{NH}_3$  emissions from sewage sludge used as fertilizer, was updated in the 2021 submission. The former estimation used the total N in sewage sludge multiplied by  $\text{frac}_{\text{gas}}^{\text{m}}$ . The  $\text{frac}_{\text{gas}}^{\text{m}}$  was equal to volatilised N in animal manure applied, and dung and urine deposited by grazing animals as fraction of total N in the manure applied and dung and urine deposited (kg  $\text{NH}_3\text{-N}$  +  $\text{NO}_x\text{-N}$ )/(kg N applied or deposited). The new estimation uses the EEA Guidebook 2019 default emission factor for sewage sludge 0.13 kg  $\text{NH}_3$ /kg N applied. The impact on indirect  $\text{N}_2\text{O}$  emission is described in chapter 10.

##### $\text{NO}_x$

The nitrogen in sewage sludge applied to soil has been multiplied with the default tier 1 emission factor to estimate the nitric oxide emissions.

#### 5.4.1.3.2 Activity data

##### $\text{N}_2\text{O}$ , $\text{NH}_3$ and $\text{NO}_x$

Statistics Norway (wastewater statistics) annually gives values for the amount of sewage sludge, and the fraction of the sewage sludge that is applied on fields. The N-content in the

sludge is given in Statistics Norway (2001), and the same value of 2.82% is used for all years.

#### 5.4.1.3.3 Emission factors

##### N<sub>2</sub>O

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg N applied (IPCC 2006) has been used.

##### NH<sub>3</sub>

The EEA Guidebook 2019 default emission factor for sewage sludge of 0.13 kg NH<sub>3</sub>/kg N applied has been used.

##### NO<sub>x</sub>

The tier 1 default emission factor of 0.04 kg NO<sub>2</sub>/kg fertilizer-N applied (EEA 2019) has been used.

### **5.4.1.4 Other organic fertilizers applied to soils, 3Da2**

#### 5.4.1.4.1 Methodological issues

##### N<sub>2</sub>O

Emissions of N<sub>2</sub>O from other organic fertilizers applied to soils are estimated by multiplying estimated amounts of N in organic fertilizers with the IPCC default emission factor for N applied to agricultural soils.

##### NH<sub>3</sub>

The calculation of NH<sub>3</sub> emissions from other organic fertilizers applied to soils, was updated in the 2021 submission. The former estimation used the estimated amounts of N in organic fertilizers multiplied with the frac<sub>gasm</sub>-factor. Frac<sub>gasm</sub> was equal to volatilised N in animal manure applied and dung and urine deposited by grazing animals as fraction of total N in the manure applied and dung and urine deposited (kg NH<sub>3</sub>-N + NO<sub>x</sub>-N)/(kg N applied or deposited). The new estimation uses the EEA Guidebook 2019 default emission factor for other organic fertilizer 0.08 kg NH<sub>3</sub>/kg N applied. The impact on indirect N<sub>2</sub>O emission is described in chapter 10.

##### NO<sub>x</sub>

The amount of nitrogen in other organic fertilizers applied to soil has been multiplied with the default tier 1 emission factor.

#### 5.4.1.4.2 Activity data

##### N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub>

The annual amount of nitrogen in other organic fertilizers applied in agriculture during the period 1990-2013 was assessed in 2014 (Aquateam COWI AS 2014). Other organic fertilizer consists of compost and organic fertilizer from composting and biogas plants based on food waste, in addition of meat and bone meal (PAP) and sludge from land-based aquaculture facility in agriculture. This was a practically non-existent source of nitrogen before 2000. Since then, it has varied over the years. One important reason for the inter-annual variations is changes in regulations for the usage of meat and bone meal as fertilizer on agriculture land, which has resulted in significant inter-annual variations.

Other organic fertilizers applied to soils is a small emission source. Emissions in 2019 were estimated to less than 0.01 ktonnes N<sub>2</sub>O, or approx. 0.006% of total GHG emissions.

#### 5.4.1.4.3 Emission factors

##### N<sub>2</sub>O

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg N applied (IPCC 2006) has been used.

##### NH<sub>3</sub>

The EEA Guidebook 2019 default emission factor for other organic fertilizer of 0.08 kg NH<sub>3</sub>/kg N applied has been used.

##### NO<sub>x</sub>

The tier 1 default emission factor of 0.04 kg NO<sub>2</sub>/kg fertilizer-N applied (EEA 2019) has been used.

### **5.4.1.5 Urine and dung deposited by grazing animals, 3Da3**

#### 5.4.1.5.1 Methodological issues

##### N<sub>2</sub>O

The fraction of the total amount of animal manure produced that is droppings on pastures is given by national data for the distribution of manure to different storage systems and data for pasture times (Table 5.17). The amount of N deposited during grazing is multiplied with the IPCC default emission factor (IPCC 2006).

##### NH<sub>3</sub>

Animal population data, data for pasture times, and factors for the nitrogen amount in excreta for different animal categories give the nitrogen amounts for the animal categories on pastures. Specific emission factors by animal category are used.



#### 5.4.1.5.2 Activity data

##### N<sub>2</sub>O and NH<sub>3</sub>

Data for time on pasture and share of animals on pasture are collected from the Sample Survey in Statistics Norway 2001 (Statistics Norway 2002) and from TINE BA (TINE BA Annually). The data from TINE BA comprises pasture data for goats and milking cows. All other pasture data is from the Sample survey 2001 (Statistics Norway 2002).

How the amount of nitrogen in animal manure and the fraction of nitrogen amount that goes to pasture is estimated is further described in section 5.1.2 and 5.3.1. How the animal population is estimated is described in Section 5.1.1 and Annex VIII.

#### 5.4.1.5.3 Emission factors

##### N<sub>2</sub>O

The emissions of N<sub>2</sub>O from animals on pastures are calculated using the IPCC default emission factors of 0.02 kg N<sub>2</sub>O-N/kg N for cattle, poultry and pigs, and of 0.01 kg N<sub>2</sub>O-N/kg N for other animal groups (IPCC 2006).

##### NH<sub>3</sub>

The emission factors used for the calculation of the NH<sub>3</sub> emissions from grazing animals are shown in Table 5.26. These are the same as the emission factors recommended in EEA (2019).

| Table 5.26 Ammonia emission factors from droppings from grazing animals on pasture. |                               |
|-------------------------------------------------------------------------------------|-------------------------------|
|                                                                                     | NH <sub>3</sub> loss,% of TAN |
| Dairy cattle                                                                        | 14%                           |
| Suckling cows                                                                       | 14%                           |
| Young beef cattle                                                                   | 14%                           |
| Swine                                                                               | 31%                           |
| Horses                                                                              | 35%                           |
| Goats                                                                               | 9%                            |
| Sheep                                                                               | 9%                            |
| Fur animals                                                                         | 9%                            |
| Deer                                                                                | 14%                           |
| Reindeer                                                                            | 14%                           |

Source: EEA (2019). For deer and reindeer EF for dairy cattle is used

#### 5.4.1.6 *N<sub>2</sub>O from crop residues, 3Da4*

##### 5.4.1.6.1 Methodological issues

N<sub>2</sub>O emissions associated with crop residue decomposition are estimated using the IPCC tier 1 approach (IPCC 2006) but with some national factors. Some country specific factors are given for fraction of dry matter, fraction of total area that is renewed annually, ratio of above-ground and below ground residues to harvested yield, N content of above-ground and below-ground residues and fraction of above ground residues removed from the field. The national factors are documented in Grønlund et al. (2014). In the development of national factors, residues from perennial grass and grass-clover mixtures were prioritized, in addition to the cereal species; wheat, barley and oats, which combined constitute about 85 percent of the total agricultural crop residues. For other productions, the IPCC default factors (IPCC 2006) are assumed to be sufficiently representative.

The factors were calculated from the sale statistics for clover seeds, area statistics of meadows of different age classes, area statistics of renewed meadow, and research results on clover and N content in meadow, and yield and N content of straw in Norway.

Based on area statistics on renewed meadows the  $\text{Frac}_{\text{Renew}}$  has been estimated to 0.1.

About 75 percent of the meadows have been renewed with a mixture of grass and clover seeds, but only about 55 percent of 1- and 2-year-old meadow areas can be considered as grass-clover mixtures with more than 5 percent clover. The mean clover share in the grass-clover mixtures has been estimated to about 20 percent. The clover share is lower in older meadow, but the content in the first years is more representative for the total crop residues produced during the lifetime of the meadow.

Above-ground crop residues contain both leaves and stubbles, while below ground residues are assumed to contain only roots. The N contents of above-ground and below-ground crop residues ( $N_{\text{AG}}$  and  $N_{\text{BG}}$ ) have been estimated to 0.015 and 0.011 respectively for meadow without clover and 0.019 and 0.016 respectively for meadow with 20 percent clover share. A possible higher clover shares in the beginning of the 1990s has not had a significant influence on N fractions of grass-clover mix in meadows.

Straw harvested for purposes as feed, beddings and energy ( $\text{FRAC}_{\text{Remove}}$ ) has been estimated to 0.13 of the total straw production.

For wheat, barley and oats the ratio of above-ground residues (straw) to harvested grain yield ( $R_{AG}$ ) has been estimated to 0.95, 0.76 and 0.92 respectively, and the N fraction in the straw ( $N_{AG}$ ) has been estimated to 0.0042, 0.005 and 0.033 respectively (Grønlund et al. 2014). The fraction of crop residue burned on field was updated in 2012 by the Norwegian Agricultural Authorities<sup>28</sup>. This reduced the fraction for 2011 from 7.5 to 4%.

$$F_{CR} = \sum_T \left[ Crop_{(T)} * Frac_{DM(T)} * (1 - Frac_{BURN(T)}) * Frac_{RENEW(T)} \right. \\ \left. * [R_{AG(T)} * N_{AG(T)} * (1 - Frac_{REMOVE(T)}) + R_{BG(T)} * N_{BG(T)}] \right]$$

Where:

$F_{CR}$  = N in crop residue returned to soils (tonnes)

$Crop_T$  = Annual crop production of crop (tonnes)

$Frac_{DM}$  = Dry matter content

$Frac_{BURN}$  = Fraction of crop residue burned on field

$Frac_{RENEW}(T)$  = fraction of total area under crop T that is renewed annually

$R_{AG}(T)$  = ratio of above-ground residues dry matter ( $AGDM(T)$ ) to harvested yield for crop T ( $kg\ d.m.$ )<sup>-1</sup>,

$N_{AG}(T)$  = N content of above-ground residues for crop T,  $kg\ N\ (kg\ d.m.)^{-1}$

$Frac_{REMOVE}$  = Fraction of crop residue removed for purposes as feed beddings and energy

$R_{BG}(T)$  = ratio of below-ground residues to harvested yield for crop T,  $kg\ d.m.\ (kg\ d.m.)^{-1}$

$N_{BG}(T)$  = N content of below-ground residues for crop T,  $kg\ N\ (kg\ d.m.)^{-1}$

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<sup>28</sup> Johan Kollerud, Norwegian Agricultural Agency, unpublished material 2012.

| <b>Table 5.27 Factors used for the calculation of the nitrogen content in crop residues returned to soils.</b> |                  |                    |                       |                 |                 |                        |                 |                 |
|----------------------------------------------------------------------------------------------------------------|------------------|--------------------|-----------------------|-----------------|-----------------|------------------------|-----------------|-----------------|
|                                                                                                                | Share of meadows | Frac <sub>DM</sub> | Frac <sub>RENEW</sub> | R <sub>AG</sub> | N <sub>AG</sub> | Frac <sub>REMOVE</sub> | R <sub>BG</sub> | N <sub>BG</sub> |
| Perennial grasses                                                                                              | 0.45             | 0.9                | 0.1                   | 0.3             | 0.015           | 0                      | 1.04            | 0.011           |
| Grass-clover mixtures                                                                                          | 0.55             | 0.9                | 0.1                   | 0.3             | 0.019           | 0                      | 1.04            | 0.013           |
| Wheat                                                                                                          |                  | 0.85               | 1                     | 0.95            | 0.0042          | 0.13                   | 0.47            | 0.009           |
| Rye                                                                                                            |                  | 0.85               | 1                     | 1.1             | 0.005           | 0.13                   | 0.46            | 0.011           |
| Rye wheat                                                                                                      |                  | 0.85               | 1                     | 1.09            | 0.006           | 0.13                   |                 | 0.009           |
| Barley                                                                                                         |                  | 0.85               | 1                     | 0.76            | 0.005           | 0.13                   | 0.39            | 0.014           |
| Oats                                                                                                           |                  | 0.85               | 1                     | 0.92            | 0.0033          | 0.13                   | 0.48            | 0.008           |
| Rapeseed                                                                                                       |                  | 0.85               | 1                     | 1.1             | 0.006           | 0.15                   | 0.46            | 0.009           |
| Potatoes                                                                                                       |                  | 0.22               | 1                     | 0.1             | 0.019           | 0                      | 0.22            | 0.014           |
| Roots for feed                                                                                                 |                  | 0.22               | 1                     | 0.1             | 0.019           | 0                      |                 | 0.014           |
| Green fodder (non-N fix)                                                                                       |                  | 0.9                | 1                     | 0.3             | 0.015           | 0                      | 0.70            | 0.012           |
| Vegetables                                                                                                     |                  | 0.22               | 1                     | 0.1             | 0.019           | 0                      | 0.22            | 0.014           |
| Peas                                                                                                           |                  | 0.91               | 1                     | 1.1             | 0.008           | 0                      | 0.40            | 0.008           |
| Beans                                                                                                          |                  | 0.91               | 1                     | 1.1             | 0.008           | 0                      | 0.40            | 0.008           |

Source: Grønlund et al. (2014)

#### 5.4.1.6.2 Activity data

As activity data for the estimations of emissions of N<sub>2</sub>O from crop residues are annual crop yield statistics from Statistics Norway used.

#### 5.4.1.6.3 Emission factors

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg N applied (IPCC 2006) has been used.

### 5.4.1.7 N<sub>2</sub>O from mineralization/immobilization associated with loss/gain of soil organic matter, 3Da5

#### 5.4.1.7.1 Methodological issues

Cropland remaining cropland result in positive SOC stock changes in the mineral soil pool; thus, no N<sub>2</sub>O emissions are reported from this sub-category. For more information, see NIR Chapter 6.13 Direct N<sub>2</sub>O from N mineralization and immobilization – 4(III).

#### **5.4.1.8 *N<sub>2</sub>O from cultivation of organic soils, 3Da6***

##### **5.4.1.8.1 Methodological issues**

Large N<sub>2</sub>O emissions occur as a result of cultivation of organic soils (histosols) due to enhanced mineralization of old, N-rich organic matter (IPCC 2006). The emissions are calculated using the IPCC default emission factors, and an estimation of the area of cultivated organic soil in Norway.

##### **5.4.1.8.2 Activity data**

The area estimates of cultivated organic soils is given from the Norwegian Institute of Bioeconomy Research (NIBIO) and are normally consistent with the area used in the LULUCF sector and includes all areas with organic soils of cropland remaining cropland, grassland remaining grassland, land converted to cropland and land converted to grassland. For the 2021 submission the 2020 area figures are used for 3Da6, and LULUCF and agricultural data are not consistent. This was due to change in methodology for LULUCF which made delay in data deliverance to the agriculture sector. More information about the methodology used for estimation of this area is given in the LULUCF Chapter 6.3.2.

##### **5.4.1.8.3 Emission factors**

Emissions occurring as a result of cultivation of organic soils are calculated using the IPCC default emission factor of 13 kg N<sub>2</sub>O-N/ha per year for cropland and 1.6 kg N<sub>2</sub>O-N/ha per year for grassland (Borgen et al. 2014).

#### **5.4.1.9 *Indirect N<sub>2</sub>O emissions from atmospheric deposition, 3Db1***

##### **5.4.1.9.1 Methodological issues**

Atmospheric deposition of nitrogen compounds fertilizes soils and surface waters and enhances biogenic N<sub>2</sub>O formation. Deposition of nitrogen are assumed to correspond to the amounts of NH<sub>3</sub> and NO<sub>x</sub> that volatilises during the spreading of synthetic fertilizers, manure, sewage sludge and other organic fertilizers, and NH<sub>3</sub> volatilisation from pastures. The N<sub>2</sub>O emissions are calculated by multiplying the amount of N from deposition with the IPCC default emission factor (IPCC 2006).

##### **5.4.1.9.2 Activity data**

Information about the estimation of NH<sub>3</sub> and NO<sub>x</sub> from spreading of synthetic and organic fertilizers and the estimation of NH<sub>3</sub> volatilisation from pastures are given in NIR section 5.4.1.1- 5.4.1.5.

#### 5.4.1.9.3 Emission factors

##### N<sub>2</sub>O

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/(kg NH<sub>3</sub>-N+NO<sub>x</sub>-N volatilized) (IPCC 2006) is used to calculate indirect emissions of N<sub>2</sub>O from volatilized NH<sub>3</sub> and NO<sub>x</sub>.

#### **5.4.1.10 Indirect N<sub>2</sub>O emissions from leaching and run-off, 3Db2**

##### 5.4.1.10.1 Methodological issues

A considerable amount of fertilizer nitrogen is lost from agricultural soils through leaching and run-off. Fertilizer nitrogen in ground water and surface waters enhances biogenic production of N<sub>2</sub>O as the nitrogen undergoes nitrification and denitrification. The fraction of the fertilizer and manure nitrogen lost to leaching and surface runoff may vary depending on several factors. A default value of 30% is proposed (IPCC 2006), but in the Norwegian inventory a national factor of 22% is used that is believed to better reflect Norwegian conditions (Rivedal 2022). This estimation was based on data from the Agricultural Environmental monitoring program (JOVA). The overall Frac<sub>leach</sub> estimated in this study was 22% of the N applied. This value is a median of Frac<sub>leach</sub> for every year during the monitoring period and for each of eight catchments with different production systems. The JOVA-program includes catchment and field study sites representing typical situations in Norwegian agriculture with regard to production system, management, intensity, soil, landscape, region and climate. The median for the catchments was 26%, but the weighted Norwegian factor based on area distribution and type of production condition was 22%.

The amount of nitrogen lost to leaching is multiplied with the IPCC default emission factor to calculate the emission of N<sub>2</sub>O (IPCC 2006).

Nitrogen sources included are inorganic fertilizers, manure, sewage sludge and other organic fertilizers spread on fields, crop residues, and droppings from grazing animals.

##### 5.4.1.10.2 Activity data

Information about the estimation of the nitrogen amounts from spreading of synthetic and organic fertilizers and from pastures and crop residues are given in NIR section 5.4.1.6.

##### 5.4.1.10.3 Emission factors

##### N<sub>2</sub>O

The IPCC default emission factor of 0.0075 kg N<sub>2</sub>O-N/kg N lost to leaching/runoff is used (IPCC 2006).

## 5.4.2 Uncertainties and time-series consistency

### 5.4.2.1 Activity data

There are several types of activity data entering the calculation scheme:

*Sales of nitrogen fertilizer:* The data is based on sales figures for one year (The Norwegian Food Safety Authority). The uncertainty in the sales figures is within  $\pm 5\%$  (Rypdal & Zhang 2000). In addition, there is a possible additional error because sale does not necessarily equal consumption in a particular year due to storage.

*Amount of nitrogen in manure:* The figures are generated for each animal type, by multiplying the number of animals with a nitrogen excretion factor. The nitrogen excretion factors are uncertain. However, due to monitoring of nitrogen leakage in parts of Norway, the certainty has been improved over time. The range is considered to be within  $\pm 15\%$  (Rypdal & Zhang 2000). The uncertainty is connected to differences in excreted N between farms in different parts of the country, that the surveyed farms may have not been representative, general measurement uncertainty and the fact that fodder and feeding practices have changed since the factors were determined.

The uncertainty connected to the estimate of the amount of manure is higher than for the amount of synthetic fertilizer used.

*Fate of manure:* There is significant uncertainty connected to the allocation of manure between what is used as fertilizer and droppings on pastures.

*Atmospheric deposition of agricultural  $\text{NH}_3$  emissions:* The data is based on national figures for  $\text{NH}_3$  emission from agriculture. These are within  $\pm 30\%$  (Rypdal & Zhang 2000)

*Leakage of nitrogen:* The upper limit for the leakage is the applied nitrogen. The uncertainty is roughly about  $\pm 70\%$  (Rypdal & Zhang 2000).

### 5.4.2.2 Emission factors

#### $\text{N}_2\text{O}$

Uncertainty estimates used for the  $\text{N}_2\text{O}$  emission factors are given in Annex II.

#### $\text{NH}_3$

The uncertainty in the estimate of  $\text{NH}_3$  emissions from use of fertilizer is assessed to be about  $\pm 20\%$  (Rypdal & Zhang 2001). This uncertainty could be lower if better data on fertilizer composition were obtained. The uncertainty is higher for animal manure,  $\pm 30\%$  (Rypdal & Zhang 2001). This is due to uncertainties in several parameters including fraction of manure left on pastures, amount of manure, conditions of storage, conditions of

spreading and climate conditions (Rypdal & Zhang 2001). Other factors that could lead to uncertainty are variation in storage periods, variation in house types and climate, and variation in manure properties.

#### 5.4.3 Category-specific QA/QC and verification

In 2006, the methodology used for estimating  $N_2O$  from crop residues has been changed to the method Tier 1b (IPCC 2000). The new method is more detailed and is supposed to better reflect the real emissions than the earlier used national method. In 2014, the methodology was further enhanced with emphasis on nitrogen in residues in grass and in grain production (Grønlund et al. 2014).

There was a strong price increase for nitrogen fertilizer, which caused a stock building in 2008 and corresponding lower purchases in 2009. The calculation of  $N_2O$  emissions from use of nitrogen fertilizer is based on sales figures for each year. To correct for this, a transfer of fertilizer from 2008 to 2009 was made in the calculations.

New factors for nitrogen excretion from animals and a revision of animal statistics has been made in 2012, to better reflect the actual nitrogen excretion from each animal category and to have a more correct linkage between the nitrogen excretion factors used and the different animal categories.

In the project in 2012, when the Norwegian University of Life Sciences (NMBU) updated the Norwegian nitrogen excretion factors for the different animal species, comparisons were made with the corresponding factors used in Sweden, Denmark and Finland and with IPCC default factors as a verification of the Norwegian factors (Karlengen et al. 2012).

A new  $Frac_{leach}$  factor was estimated in a study by Bioforsk (Norwegian Institute for Agricultural and Environmental Research) in 2012 (Bechmann et al. 2012). The updated factor is based on data from the Agricultural Environmental monitoring program (JOVA). A project with the aim to revise the Norwegian  $CH_4$  conversion factors (MCF) for the manure storage systems in use was conducted at the Norwegian University of Life Sciences (NMBU) in 2013. The maximum  $CH_4$  producing capacity ( $B_o$ ) was also revised for cattle manure.

An update of the manure distribution between different manure management systems has been made for the  $N_2O$  emissions estimates based on the results of a survey conducted by Statistics Norway in 2013-2014 (Gundersen & Høidal 2015) and 2015-2018 (Kolle & Oguz-Alper 2020). Data from the manure survey of 2013 was implemented in the estimations of



N<sub>2</sub>O and CH<sub>4</sub> emissions from manure in the 2015 submission, and in the 2016 submission for NH<sub>3</sub>.

In the 2015 submission, the area of cultivated organic soils has been revised back to 1990 based on an assessment by the Norwegian Institute of Bioeconomy Research. The new area estimates better reflect the land use changes measured in the national forest inventory.

In 2018, the model for calculating emissions of N<sub>2</sub>O, NH<sub>3</sub> and NO<sub>x</sub> from manure was revised. As part of the revision of the nitrogen model undertaken in 2018, a review was undertaken of the Norwegian emissions factors compared to those used in other Nordic and Northern European countries.

In 2021, the national factor FracLEACH has been reviewed by NIBIO. The results of the revision is documented in (Rivedal 2022) (Rivedal 2022). The earlier used national factor for FracLEACH was 22% (Bechmann et al. 2012). This estimation was based on data from the Agricultural Environmental monitoring program (JOVA). The factor was a median of FracLeach for every year during the monitoring period and for each of eight catchments representing typical situations in Norwegian agriculture with regard to production system, management, intensity, soil, landscape, region and climate. The factor was in 2022 recalculated, and the median for the catchments was now 26%, but the weighted Norwegian factor based on area distribution and type of production condition was 22%, so the earlier used factor for FracLeach is kept in the inventory.

#### 5.4.4 Category-specific recalculations

Indirect N<sub>2</sub>O atmospheric deposition 3Db: For 3Da2, Animal manure applied to soils there has been a change in total NH<sub>3</sub> emissions from spreading of manure due to a technical correction in the Nitrogen model. This involved that the emission from spreading was corrected. The former version did not cover all areas where manure was spread. The updated version gave 11% higher NH<sub>3</sub> emissions on average from 1990 to 2020 compared to the latest submission. For NO<sub>x</sub> it led to a smaller change by 0.3 % higher emissions.

For indirect N<sub>2</sub>O, atmospheric deposition from grazing the time series was also changed in 2023 submission. In 2022 the Nitrogen model was corrected due to a wrong calculation of NO<sub>x</sub> that affected the calculation of atmospheric deposition from grazing.

An error correction for TAN for “heifers for breeding” also changed the NH<sub>3</sub> and NO<sub>x</sub> basis.

These changes as a total led to 2 per cent higher indirect N<sub>2</sub>O emissions by average from 1990 to 2020 compared to previous submission.

For 3Da2 updated figures from Statistics Norway census of agriculture 2020 gave new information about spreading practice and incorporation time. The whole time series back to 1990 was revised since inconsistencies in earlier calculation were discovered. This only led to minor changes in the N<sub>2</sub>O emissions from 1990 to 2018, by minus 0.3 per cent on average. For 2019 and 2020, the years that were affected by new activity data on spreading techniques and incorporation time, gave 0.1 and 1.4 per cent higher N<sub>2</sub>O emissions compared to former submission.

For the emission of N<sub>2</sub>O from crop residues in 3Da4 there has been changes in the 2023 submission due to updated figures for crop production in 2020. This led to 3 per cent higher N<sub>2</sub>O emissions in 2020 compared to the 2022 submission.

For 3Da6, N<sub>2</sub>O from cultivation of organic soils, the whole time series has been recalculated due to updated area estimates for organic soils from NIBIO. This led to 0.5 per cent lower N<sub>2</sub>O emissions in average in 2020 compared to the 2022 submission.  
See Chapter 10.2.3 for more details.

#### **5.4.5 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## **5.5 Emissions from field burning of agricultural residues – 3F**

### **5.5.1 Category description**

Burning of agricultural residues gives emissions of standard non-fossil combustion products. The source contributed with 0.1% of the agricultural greenhouse gas emissions in 2021, and the emissions have been decreasing with 90% since 1990. The amount of crop residues burned in Norway has been investigated by the Norwegian Agricultural Authorities by questionnaires in 2004 and 2012. The results of the survey in 2012 resulted in that the fraction burned for 2011 was reduced to 4%. Reasons for the reduction was that in connection with the introduction of grants for changed tillage practice (RMP-Regional Environment Programme), it was also given requirements that the straw are prohibited to be burned or only allowed to be burn in the spring. Many municipalities have also banned

the burning of straw, and in these cases, dispensation must be applied for before the farmers are allowed to burn crop residues.

#### 5.5.1.1 Methodological issues

CH<sub>4</sub>, N<sub>2</sub>O

Emissions from the burning of crop residues are being calculated in accordance with a Tier 1 approach (EEA 2019):

$$E_{\text{Pollutant}} = AR_{\text{residue\_burnt}} * EF_{\text{Pollutant}}$$

Where:

$E_{\text{Pollutant}}$  = emission (E) of pollutant

$AR_{\text{residue\_burnt}}$  = activity rate (AR), mass of residue burnt (dry matter)

$EF_{\text{Pollutant}}$  = emission factor (EF) for pollutant

#### 5.5.1.2 Activity data

The calculation of the annual amount of crop residue burned on the fields is based on crop production data for cereals and rapeseed from Statistics Norway and estimates of the fraction burned ( $Frac_{\text{BURN}}$ ) made by the Norwegian Crop Research Institute and Statistics Norway (chapter 5.4.1.6). For cereals, a water content of 15% is used (Statistics Norway). The activity data is consistent with the data used in the estimations of N<sub>2</sub>O from crop residues.

**Table 5.28 Emission factors for agricultural residue burning.**

| Components       | Emission factors | Unit                                  | Source      |
|------------------|------------------|---------------------------------------|-------------|
| CH <sub>4</sub>  | 2.7              | kg/ tonnes crop residue (d.m.) burned | (IPCC 2006) |
| N <sub>2</sub> O | 0.07             | kg/ tonnes crop residue (d.m.) burned | (IPCC 2006) |

#### 5.5.2 Uncertainties and time-series consistency

Uncertainty estimates are given in Annex II.

#### 5.5.3 Category-specific QA/QC and verification

In 2002, the emissions of CH<sub>4</sub> and N<sub>2</sub>O, from agricultural residual burning were included in the Norwegian inventory. The time series were included, but it should be noted that the figures for the earlier years have a higher uncertainty than the more recent years. The amount of crop residues burned in Norway has been investigated by questionnaires in 2004 and 2012.

#### 5.5.4 Category-specific recalculations

Updated activity data for the year 2020 lead to approximately 5 per cent higher emissions for CH<sub>4</sub> and N<sub>2</sub>O in 2020 compared to earlier submission.

#### 5.5.5 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

### 5.6 Emissions from liming – 3G (Key category for CO<sub>2</sub>)

#### 5.6.1 Category description

Liming of agricultural soils and lakes gives emissions of CO<sub>2</sub>. The source contributed with about 3% of the agricultural greenhouse gas emissions in year 2021, and the emissions have decreased with 47% since 1990.

CO<sub>2</sub> emissions from liming is key category according to Approach 1 key category analysis. It is common to lime Norwegian soils because of the low buffer capacity of most soils. The use of limestone is more popular than dolomite. Also, for several years many lakes in the southern parts of Norway have been limed to reduce the damages from acidification.

Estimated emissions from liming on agricultural lands have reduced since 1990, whereas liming of lakes has been relatively constant.

##### 5.6.1.1 Methodological issues

A Tier 1 method was used with specific emission factors for limestone and dolomite.

##### 5.6.1.2 Activity data

Statistics on consumption of liming applied to agricultural soils are derived from the Norwegian Food Safety Authority. The statistics are based on reports from commercial suppliers of lime. The amount of lime applied to lakes was collected from the Norwegian Environment Agency. It was not possible to separate the amount of lime originating as limestone or dolomite for lakes for the whole time-series.

##### 5.6.1.3 Emission factors

The default emission factor values provided by IPCC are 0.12 Mg CO<sub>2</sub> C Mg<sup>-1</sup> for limestone and 0.13 Mg CO<sub>2</sub> C Mg<sup>-1</sup> for dolomite. For limestone this is equal to emissions of 0.44 Mg CO<sub>2</sub> per Mg CaCO<sub>3</sub> applied. The emission factors are based on the stoichiometry of the lime types.

For emissions estimates for liming on lakes, the emissions factor for limestone is used ( $0.12 \text{ Mg CO}_2 \text{ C Mg}^{-1}$ ), as only the total amount of lime was available.

### 5.6.2 Uncertainties and time-series consistency

The amount of limestone and dolomite used is expected to be known with an uncertainty on  $\pm 5$  percent and the emission factor with an uncertainty of  $\pm 10\%$ .

### 5.6.3 Category-specific recalculations

There have been no, recalculations performed for this source category this year.

### 5.6.4 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 5.7 Emissions from urea application – 3H

### 5.7.1 Category description

Urea application on agriculture soils is a minor source of  $\text{CO}_2$  emissions in the inventory and contributes with about 0.002% of the agriculture greenhouse gas emissions in 2021.

#### 5.7.1.1 Methodological issues

Application of urea results in an emission of  $\text{CO}_2$ . Norway uses a Tier 1 methodology. Annual  $\text{CO}_2$  emissions from urea fertilisation are estimated according to equation 11.13 (IPCC 2006):

$$\text{CO}_2\text{-C Emission} = M \cdot \text{EF},$$

where:

$\text{CO}_2\text{-C Emission}$  = annual C emissions from urea application, tonnes C  $\text{yr}^{-1}$

$M$  = annual amount of urea fertilisation, tonnes urea  $\text{yr}^{-1}$

$\text{EF}$  = emission factor, tonne of C (tonne of urea) $^{-1}$

#### 5.7.1.2 Activity data

Amount of urea used is received from Norwegian Food Safety Authority annually; total sale of synthetic fertilizer and is the same figure for the amount of urea used in the estimations of  $\text{NH}_3$  from use of synthetic fertilizers. The amount used is very small, and consequently this is a very small source of  $\text{CO}_2$  emissions.

#### 5.7.1.3 Emission factors

The default emission factor of 0.20 is used (IPCC 2006).

## **5.7.2 Uncertainties and time-series consistency**

### **5.7.2.1 Activity data**

The uncertainty that applies to use of mineral fertilizers on  $\pm 5$  percent are used.

### **5.7.2.2 Emission factor**

Using the Tier 1 method, it is assumed all C in the urea is lost as CO<sub>2</sub> from the atmosphere. This is a conservative approach (IPCC 2006). No uncertainty estimate is found, and Norway uses an uncertainty of  $\pm 10\%$ .

## **5.7.3 Category-specific recalculations**

There have been no recalculations performed for this source category this year.

## **5.7.4 Category-specific planned improvements**

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 6. Land-use, land-use change and forestry (CRF sector 4)

This chapter provides estimates of emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF), documentation of the implementation of guidelines given in *2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006)* (hereinafter referred to as *IPCC 2006 Guidelines*), the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC 2014a) (hereinafter referred to as *IPCC 2013 KP Supplement*), selected parts of the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014b) (hereinafter referred to as *IPCC 2013 Wetlands supplement*) and the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019), (hereinafter referred to as *IPCC 2019 Refinement*). The IPCC 2019 Refinement was accepted for use on a voluntary basis for the GHG inventory reports during COP 26 (Glasgow, Nov. 2021). A combination of the IPCC 2006 Guidelines methodologies and updated methodologies from IPCC 2019 Refinement have been utilized. The respective implemented methodologies have been determined to most accurately represent the conditions found in Norway given existing methodology, data, and resource limitations.

All calculations and analyses in this chapter, except the key category analysis (section 6.1.4), have been conducted by the Norwegian Institute of Bioeconomy Research (NIBIO).

### 6.1 Sector Overview

#### 6.1.1 Emissions and removals

The LULUCF sector can function as both a source of emissions of greenhouse gasses (GHG) CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> to the atmosphere and a sink for greenhouse gasses through the removal of atmospheric CO<sub>2</sub>. The balance of the two is net emissions or removals in the LULUCF sector. Net emissions of GHGs are reported as positive numbers, while removals of CO<sub>2</sub> are reported as negative numbers.

The LULUCF sector had a net removal of -15 497 kt CO<sub>2</sub> equivalents in 2021. These removals are substantial and equal to approximately 32% of the total emissions from all other sectors than LULUCF in the Norwegian GHG accounting. The average annual net sequestration from the LULUCF sector was about -17 685 kt CO<sub>2</sub> equivalents per year for the period 1990 – 2021.

Forest land is responsible for most of the CO<sub>2</sub> removals in the sector in 2021. In 2021 the net removals from forest land were -20 197 kt CO<sub>2</sub> equivalents (Figure 6-1). In 2021 there were net emissions from wetlands of 406 kt of CO<sub>2</sub> equivalents. Cropland was the land use category with the largest emissions at the beginning of the inventory period, with 2005 kt CO<sub>2</sub> equivalents in 1990, and the emissions increased to 2 337 kt CO<sub>2</sub> equivalents in 2021. The main source of emissions in the cropland category is drained organic soils. In 1990 grasslands had an estimated net removal of -270 kt CO<sub>2</sub> equivalents, mainly due to living biomass. Since then, the emissions have increased largely due to land-use change from forest land to grassland, resulting in net emissions of 189 kt CO<sub>2</sub> equivalents in 2021. Emissions from settlements increased from 1665 kt CO<sub>2</sub> equivalents in 1990 to 1 939 kt CO<sub>2</sub> equivalents in 2021. Croplands followed closely by settlements, are the land-use categories responsible for the largest net emissions of the six land-use categories in the LULUCF sector in 2021. No emissions are occurring for the category other lands. The carbon loss from the harvested wood products (HWP) pool was larger than the input of carbon to the pool in the period 2009 – 2016. Since 2017 there has been net annual input to the pool. The net removals from HWP were -229 kt CO<sub>2</sub> in 2021.

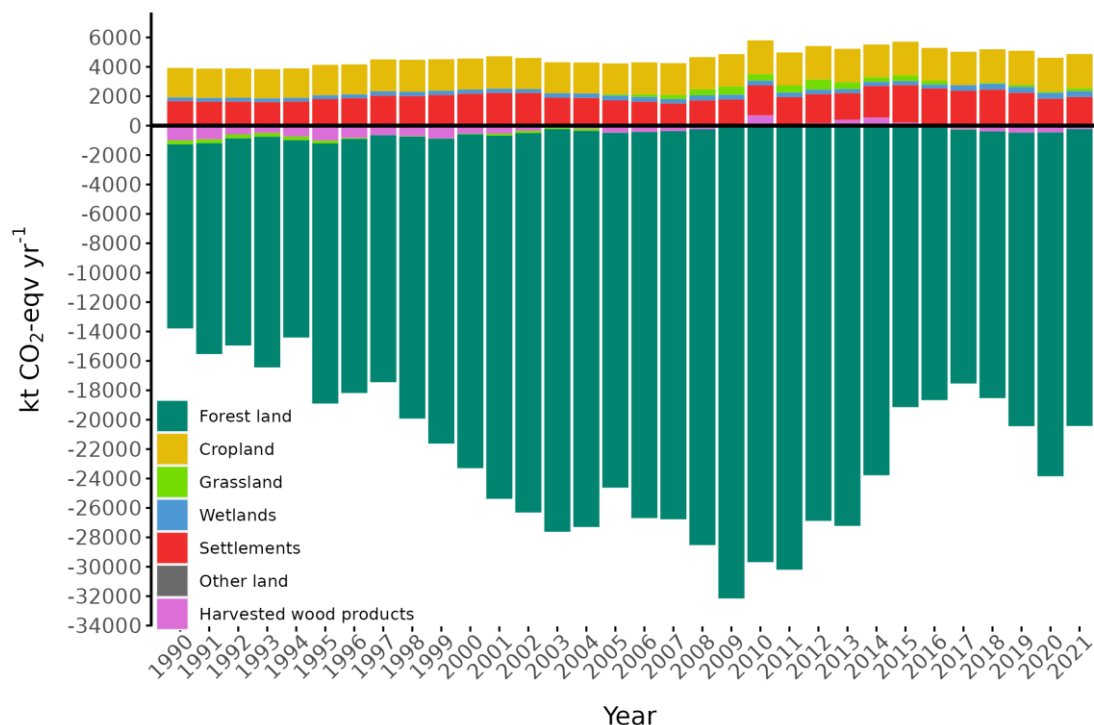


Figure 6-1 Net CO<sub>2</sub> emissions and removals (kt CO<sub>2</sub> equivalents per year) from the LULUCF sector by land-use category (forest land, cropland, grassland, wetlands, settlements, other land, and



*harvested wood products) from 1990 to 2021, including emissions of N<sub>2</sub>O and CH<sub>4</sub>. Negative values are net removals, and positive values are net emissions. Source: Norwegian Institute of Bioeconomy Research.*

Forest land was the major contributor to the net sequestration of CO<sub>2</sub> in the sector. In 2021, the total net removals in forest land were -20 416 kt CO<sub>2</sub> (Figure 6-2). Emissions from forest land remaining forest land occurred primarily from drained organic soils (1 250 kt CO<sub>2</sub>). Mineral soil on forest land remaining forest land constituted a removal of -111 kt CO<sub>2</sub>. Living biomass was the primary contributor to sequestration with 71.4% (-14 655 kt CO<sub>2</sub>) of the total removals for forest land remaining forest land. The dead wood and litter pools contributed with 4.7% (-968 kt CO<sub>2</sub>) and 23.3% (-4 785 kt CO<sub>2</sub>) to the total C sequestration on forest land remaining forest land, respectively. Land converted to forest land contributed with removals of -1 147 kt CO<sub>2</sub>, primarily due to sequestration in litter (-582 kt CO<sub>2</sub>), dead wood (-379 kt CO<sub>2</sub>), living biomass (-184 kt CO<sub>2</sub>), and mineral soil (-19 kt CO<sub>2</sub>) pool. Emissions occurred on drained organic soil (17 kt CO kt CO<sub>2</sub>).

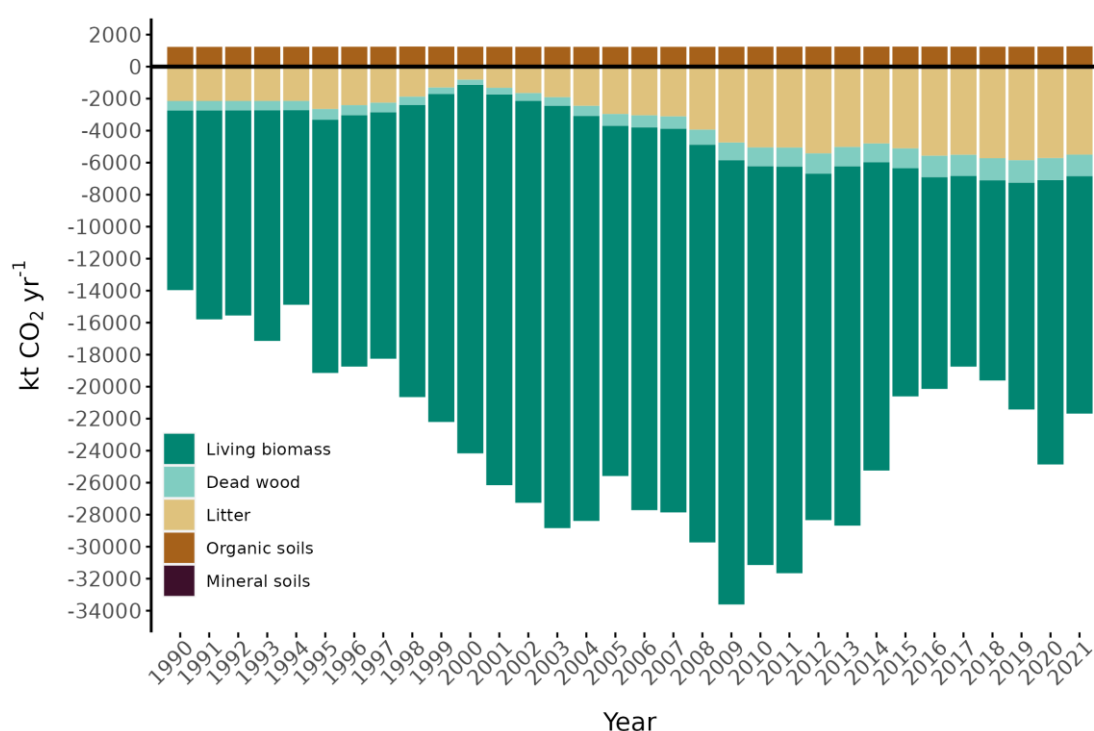


Figure 6-2 Emissions and removals of CO<sub>2</sub> on forest land from organic and mineral soil, dead wood, litter, and living biomass, 1990 -2021. Negative values are net removals, and positive values are net emissions. Source: Norwegian Institute of Bioeconomy Research.

Since 1989, the C stocks in living biomass in the LULUCF sector have increased significantly by around 45% (Table 6.1). This increase is mainly due to the increase in the growing stock of forest land (Figure 6-3).

**Table 6.1 C stocks in 1989 and 2019 and differences in C stocks compared to 1989 as a total for all land-use categories, including associated uncertainties.**  
The estimates are based on the sample plots in the lowlands outside Finnmark (>16 000 plots). SE = standard error.

| Year  | C stock (kt) | C stock difference to 1989 (kt) | 2 SE (%) of C stock difference to 1989 |
|-------|--------------|---------------------------------|----------------------------------------|
| 1989  | 316 817      | -                               | -                                      |
| 2019* | 460 259      | 143 442                         | 6                                      |

\*The estimates are based on the last five years sampled in the National Forest Inventory (2017 – 2021). The estimate is, therefore, valid for mid-year 2019.

### 6.1.1.1 Annual variation in CO<sub>2</sub> removals on forest land

Forest land covers around 37% of the mainland area of Norway and is the largest land-use category with the largest annual variation in CO<sub>2</sub> removals. The C stock in tree living biomass on forest land has increased throughout the inventory period (Figure 6-3).

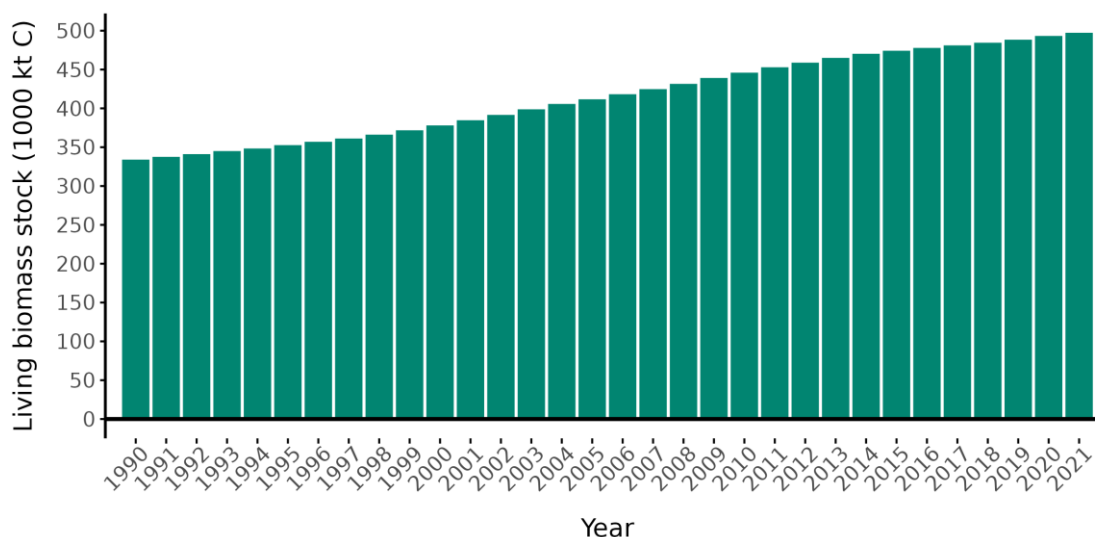


Figure 6-3 Development of the C stock in tree living biomass on forest land from 1990 -2021.

Source: Norwegian Institute of Bioeconomy Research.

The increase in C stock in tree living biomass since 1990 (Figure 6-3) is caused by several factors. The net increment increased all the years until around the year 2000, and both annual increment (Figure 6-4) and net CO<sub>2</sub>-uptake (Figure 6-2) peaked around 2009 but are still at a very high level compared to the conditions in the past 100 years. In general, the levels of annual fellings have been much lower than the annual increment, causing an accumulation of tree biomass (Figure 6-3). The increase in C stock in tree living biomass since 1990 (Figure 6-3) is caused by several factors:

The forest age-class structure is a main driver of the overall pattern of the increment. In Norway, industrial forest management combined with forest policy to rebuild the country after World War II led to intensive forest management and a large national effort to invest

in forest tree planting. That led to an increase in productive forest areas and more productive forests in already existing forests. From 1955-1992, more than 60 million trees were planted annually, with a peak of more than 100 million planted annually in the 1960s. The number of planted trees decreased from 1990 to 2003. However, since 2003 the number of planted trees has steadily increased from 19 million to 44 million trees in 2020, declining to 40 million in 2021 (Statistics Norway 2023d). Given rotation ages and stand dynamics of forests in Norway, the historic management can explain the overall pattern of a strong increase in increment in the period where a large proportion of the forest is in the prime production age (1970 - 2005) followed by a peak/stabilization of the increment when a large part of the forest start to mature and hence reduce increment (2005 - 2018) followed by a future decline that already is starting to be apparent in the data.

The climate also has a strong effect on forest growth and mortality. Since the 1980s, we have seen a strong warming trend over mainland Norway which in most years also is associated with sufficient precipitation to make for significantly improved conditions for tree growth. The climatic effect on increment is expected to have further enhanced the already expected increase in increment from 1980 and onwards. However, the exact contributions of climate versus age-effects are difficult to disentangle. Some of the fluctuations in increment over the past 15 years are also expected to be climate-driven. They can be attributed to both years with very favourable growing conditions and a few years with some summer drought.

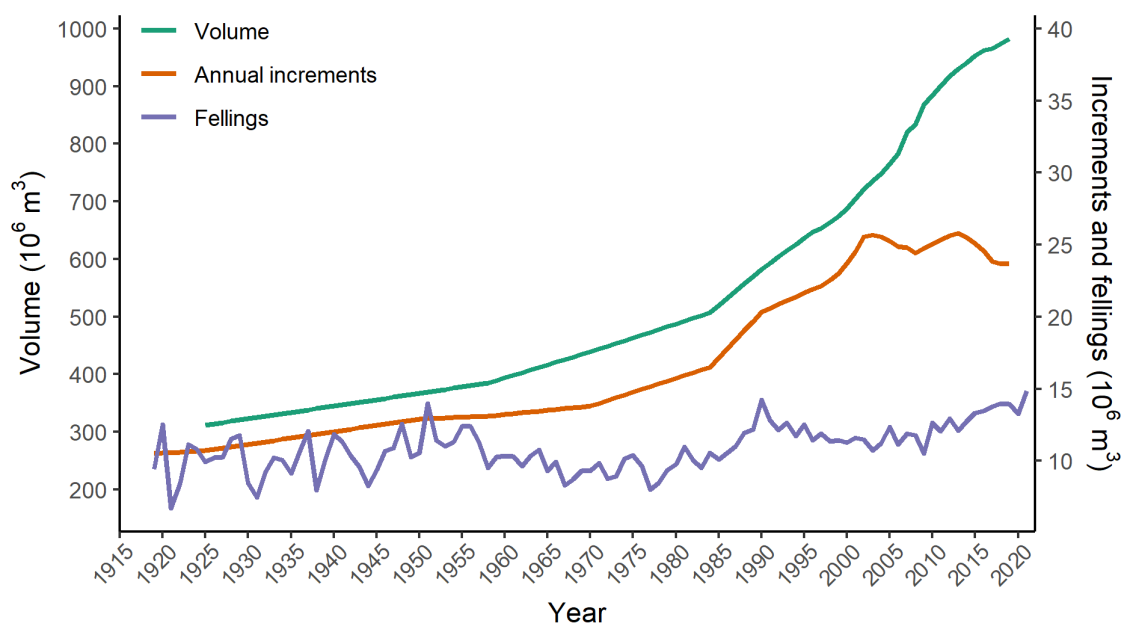


Figure 6-4 Forest fellings, annual increments, and volume (without bark) 1919–2021.

Source: Norwegian Institute of Bioeconomy Research and Statistics Norway.

### 6.1.2 Activity data

The main data source for the LULUCF sector is the National Forest Inventory (NFI) (Breidenbach et al. 2020). Data from the NFI is used to estimate the total areas of forest land, cropland, grasslands, wetlands, settlements, and other land, land-use sub-categories, and the land-use transitions between these categories. Land area estimates for the inventory have been calculated according to Approach 3, as described in chapter 3 of the IPCC 2006 Guidelines (IPCC 2006). The NFI data are also used to estimate changes in C stocks in tree living biomass and as input values for modelling changes in the C stock in dead organic matter (DOM) and mineral soil for forest land remaining forest land. DOM is the combined pool of litter and dead wood.

In the NFI, permanent sample plots are re-sampled in a 5-year cycle. Each year, 1/5 of the plots distributed throughout the country are inventoried. The same plots are inventoried again after five years, and all plots are assessed during a 5-year period. The current system with permanent plots was put in place between 1986 and 1993 and made fully operational for the cycle covering the years 1994 through 1998. Because the strict 5-year re-sampling of field plots was not fully implemented before 1994, the method used to calculate annual emissions and removals is not the same throughout the time-period, and the methods have been bridged. See section 6.3.1 for a detailed description of the method.

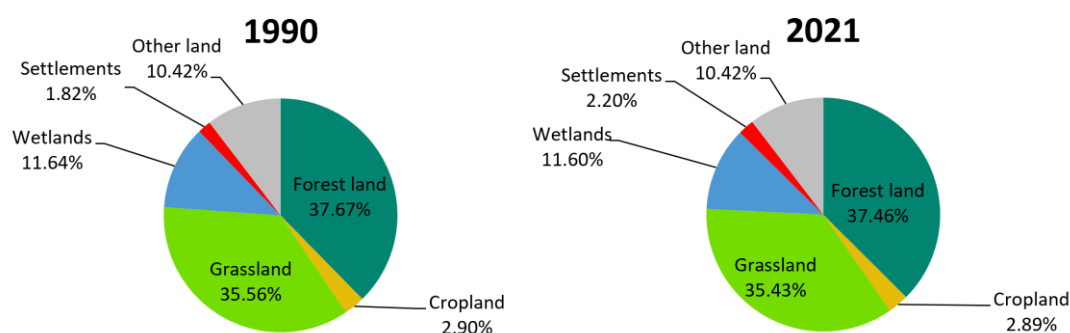
The annual changes in the tree living biomass C stock depend upon several factors, such as harvest levels and variable growing conditions due to temperature and precipitation. All these factors influence the reported annual net CO<sub>2</sub> removals from the atmosphere.

The annual fluctuation seen in CO<sub>2</sub> sequestered in dead organic matter (DOM), and mineral soil on forest land remaining forest land are influenced by annual variation in the C input data to the Yasso07 model and climatic conditions (Tuomi et al. 2009; Tuomi et al. 2011a; Tuomi et al. 2011b). Forest mineral soil and DOM carbon will undergo accumulation or losses depending on the balance between input (from vegetation) and output (decomposition, climate-driven). Carbon input to the Yasso07 model is from standing biomass (litter produced by the vegetation) and dead organic matter from natural mortality and harvest residues, including but not limited to stumps and roots from harvested trees. All these factors are influenced by the same natural, and man-made factors stated for tree living biomass, causing annual changes.

The NFI data are complemented with auxiliary data for several other sink/source categories, e.g., horticulture, arable crop types, grassland management, synthetic N fertilization, forest fires and HWP. These data are acquired from Statistics Norway, the Norwegian Agricultural Authority, the Norwegian Food Safety Authority, the Norwegian Environment Agency, The Directorate for Civil Protection and Emergency Planning and FAO forestry statistics. Detailed descriptions of these data are provided under their relevant emission categories.

#### **6.1.2.1 Land-use changes 1990-2021**

Forest land is the largest land-use category, covering nearly 37% of the mainland area of Norway. Grassland has the second largest area covering as much as 35% of the mainland, with the vast majority categorized as extensive grasslands. Net land-use changes in Norway from 1990 to 2021 are small compared to the total area. Overall, the area of settlements has increased. Forest land, grasslands, and wetlands have shown a slight decline in area, while cropland and other land have remained more or less constant (Figure 6-5)



*Figure 6-5 Area distribution of the IPCC land-use categories for 1990 and 2021. Source: Norwegian Institute of Bioeconomy Research*

The land-use changes are illustrated in Figure 6-6 and shown in the land-use conversion matrix for the whole inventory period from 1990 to 2021 (Table 6.2). Approximately 1% of the total land is in a "land-conversion" category, and the rest is in a "remaining" category. The largest changes were in the conversions from forest to settlements, and the net area of settlements has increased. Except for other land, there have been land-use conversions from all categories to forest land, cropland, and settlements. Under the convention reporting, we apply a 20-year transition period, which means that areas reside in conversion classes for 20 years before they are transferred to the remaining class.

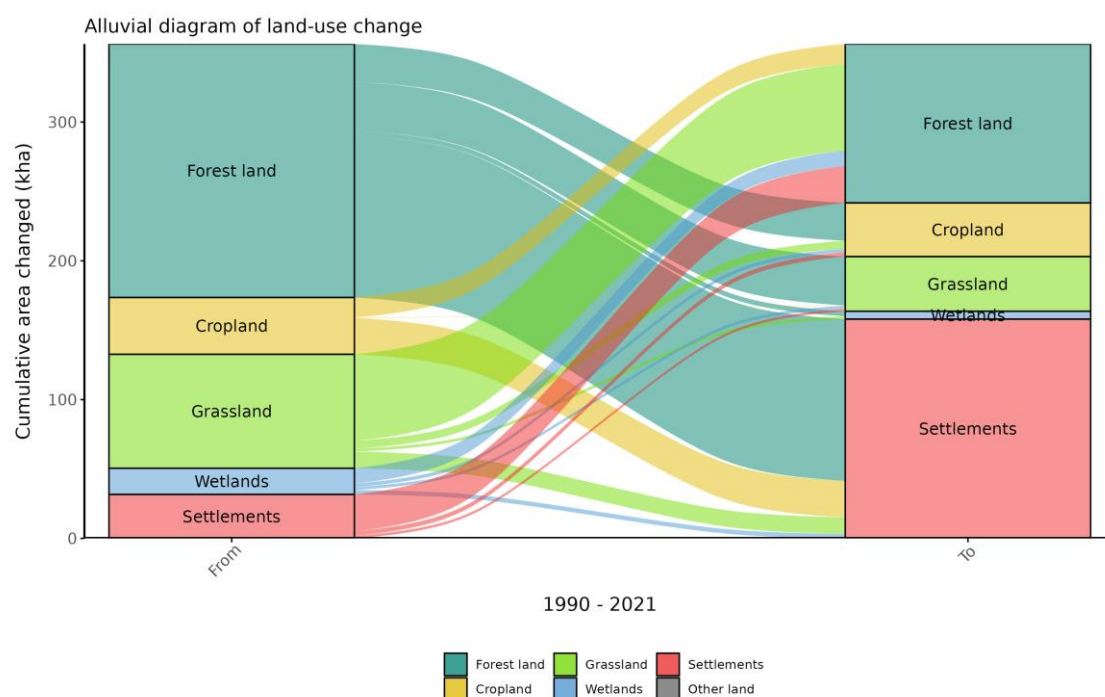


Figure 6-6 Distribution of cumulative area for land use transitions among all IPCC land use categories from 1990 to 2021. Source: Norwegian Institute of Bioeconomy Research.

**Table 6.2 Land-use change matrix for the IPCC land-use categories from 1990 to 2021.** The 20-year transition period is ignored in this table to give a full picture of all conversions that happened in the period. This results in differences in the specific area estimates in the CRF. The column Total\* here is nonetheless the same as the sum of lands to and remaining in a category reported in the CRF.

|      |             | Land-use (kha) |           |            |           |             |            |        |
|------|-------------|----------------|-----------|------------|-----------|-------------|------------|--------|
| Year |             | 2021           |           |            |           |             |            |        |
|      | Land-use    | Forest land    | Crop land | Grass land | Wet lands | Settlements | Other land | Total* |
| 1990 | Forest land | 12016          | 27        | 35         | 4         | 117         | 0          | 12199  |
|      | Cropland    | 14             | 898       | 0          | 0         | 26          | 0          | 939    |
|      | Grassland   | 62             | 6         | 11433      | 2         | 12          | 0          | 11515  |
|      | Wetlands    | 11             | 3         | 2          | 3749      | 3           | 0          | 3768   |
|      | Settlements | 27             | 3         | 2          | 0         | 553         | 0          | 584    |
|      | Other land  | 0              | 0         | 0          | 0         | 0           | 3373       | 3373   |
|      | Total*      | 12131          | 937       | 11472      | 3755      | 711         | 3373       | 32378  |

\*Differences in totals and column or row sums are due to rounding.



### 6.1.3 Uncertainties

Uncertainties of area estimates are based on a standard sampling methodology. The areas of the largest land-use categories, forest land remaining forest land and grassland, can be estimated with an uncertainty (2 standard errors) of < 2% (Table 6.3). The largest change category is forest land converted to settlements. The uncertainty estimate for this area estimate is approximately 18%. Due to the small number of NFI sample plots in several other land-use conversion categories, the relative size of the uncertainty estimates can be quite large. The absolute size of the uncertainty in those classes is nonetheless small.

The uncertainties of C stock change (CSC) estimates in tree living biomass in forest land, grasslands and wetlands were estimated as described in section 6.3.7. Estimated uncertainties are based on the sampling error. As for area estimates, the relative uncertainty estimates for CSC were quite large for small land-use categories, whereas their absolute size was comparably small (Table 6.3). For annual crop living biomass on cropland converted to lands and lands converted to croplands, the uncertainty was based on Tier 1 defaults. Similarly, for grass living biomass on grasslands converted to lands and lands converted to grasslands, uncertainties were also based on Tier 1 defaults. Uncertainty estimates for CSC estimates for the dead organic matter (DOM) pool were based on expert judgement by considering the uncertainty in the tree living biomass estimates.

**Table 6.3 Uncertainties of living biomass and dead organic matter (DOM) pools shown as total aggregated uncertainty ( $U_{total}$ ) based on the uncertainties of the C stock change (CSC) per hectare and the area estimates.**

**Area uncertainty is for combined mineral and organic soils. See Table 6.4 for area uncertainty of mineral soils which is used to obtain the total uncertainty of DOM. 2 SE means two times the standard error**

| Code | Land-use class                                 | Area <sup>a</sup> | CSC                                           | $U_{total}$ | CSC                                | $U_{total}$ |
|------|------------------------------------------------|-------------------|-----------------------------------------------|-------------|------------------------------------|-------------|
|      |                                                | 2 SE%             | Living biomass (2 SE% or default uncertainty) |             | DOM (2 SE% or default uncertainty) |             |
| 4A1  | Forest land remaining forest land <sup>b</sup> | 2                 | 23                                            | 23          | 23                                 | 23          |
| 4A2  | Cropland to forest land                        | 53                | 88                                            | 103         | 200                                | 212         |
| 4A2  | Extensive grassland to forest land             | 51                | 107                                           | 119         | 200                                | 201         |
| 4A2  | Intensive grassland to forest land             | 59                | 166                                           | 176         | 200                                | 212         |
| 4A2  | Settlements to forest land                     | 39                | 46                                            | 60          | 200                                | 201         |
| 4A2  | Unmanaged wetlands to forest land              | 66                | 89                                            | 111         | 200                                | 201         |
| 4A2  | Managed wetlands to forest land                | 102               | 121                                           | 158         | 200                                | 201         |
| 4B1  | Cropland remaining cropland <sup>c</sup>       | 0                 | 46                                            | 46          | NA                                 | NA          |
| 4B2  | Forest land to cropland                        | 42                | 83                                            | 93          | 200                                | 201         |
| 4B2  | Extensive grassland to cropland                | 200               | 75                                            | 212         | NA                                 | NA          |
| 4B2  | Intensive grassland to cropland                | 95                | 75                                            | 121         | NA                                 | NA          |
| 4B2  | Settlements to cropland                        | 141               | 75                                            | 160         | NA                                 | NA          |
| 4B2  | Managed wetlands to cropland                   | 97                | 101                                           | 140         | NA                                 | NA          |

|            |                                                   |     |     |     |     |     |
|------------|---------------------------------------------------|-----|-----|-----|-----|-----|
| <b>4C1</b> | Extensive grassland remaining extensive grassland | 3   | 21  | 21  | NA  | NA  |
| <b>4C1</b> | Intensive grassland remaining intensive grassland | 13  | 49  | 51  | NA  | NA  |
| <b>4C2</b> | Forest land to intensive grassland                | 33  | 357 | 300 | 200 | 201 |
| <b>4C2</b> | Cropland to intensive grassland                   | 200 | 101 | 224 | NA  | NA  |
| <b>4C2</b> | Settlement to extensive grassland                 | 200 | 75  | 212 | NA  | NA  |
| <b>4C2</b> | Settlement to intensive grassland                 | 161 | 71  | 176 | NA  | NA  |
| <b>4C2</b> | Unmanaged wetlands to intensive grassland         | 121 | 178 | 212 | NA  | NA  |
| <b>4D1</b> | Unmanaged Wetlands remaining unmanaged wetlands   | 8   | 36  | 37  | NA  | NA  |
| <b>4D1</b> | Managed Wetlands remaining managed wetlands       | 37  | 82  | 90  | NA  | NA  |
| <b>4D2</b> | Forest land to managed wetlands                   | 117 | 155 | 194 | 200 | 235 |
| <b>4D2</b> | Extensive Grassland to Managed Wetland            | 141 | 75  | 160 | NA  | NA  |
| <b>4E2</b> | Cropland to settlements                           | 44  | 75  | 87  | NA  | NA  |
| <b>4E2</b> | Forest land to settlements                        | 18  | 65  | 62  | 200 | 201 |
| <b>4E2</b> | Extensive grassland to settlements                | 99  | 75  | 124 | NA  | NA  |
| <b>4E2</b> | Intensive grassland to settlements                | 76  | 75  | 107 | NA  | NA  |
| <b>4E2</b> | Unmanaged wetlands to settlements                 | 100 | 109 | 148 | NA  | NA  |

<sup>a</sup> The area uncertainty is the same for living biomass and DOM. <sup>b</sup> Includes a safety margin for model errors of 1 percentage point. Uncertainty in DOM is combined for litter, dead wood, and mineral soil because of the estimation method used (all three pools are modelled and not mutually independent); therefore, the same uncertainty is used as in Table 6.4 <sup>c</sup> Area uncertainty of 0% is based on SSB data and pertains to orchards. The total area uncertainty for cropland remaining cropland is 7% based on NFI estimates.

Uncertainties for mineral soil CSC factors on land-use conversion categories were found through the combination of error propagation (combining uncertainties as given in the IPCC 2019 Refinement) and expert judgement where necessary (Table 6.4). Uncertainties in the C loss from drained organic soils were calculated using the error ranges supplied in the IPCC 2013 Wetlands supplement for all drained organic soils on forest land, cropland, grassland, wetlands - land under peat extraction, and settlement subcategories (see details under sections 6.4; 6.5; 6.6; 6.7; 6.8). In addition, an expert judgement of 50% uncertainty for C loss from instant oxidation for lands converted to infrastructure settlements was used. For each land-use change category, error propagation was applied to the weighted fraction of emissions from each IPCC climate region. The calculations for settlements also considered subcategories (see section 6.8 on settlements subcategories). The uncertainty

of the emission factors was then combined with the uncertainty of the area estimates determined by the sampling error. For two smaller classes (managed wetlands – peat extraction and orchards on croplands), the uncertainty of the area estimates is based on expert judgement as the NFI does not estimate their areas. The uncertainty in the soil type classification method, i.e., the inaccuracy of the soil maps, was ignored.

**Table 6.4 Uncertainties of the mineral soil and drained organic soil pools shown as total aggregated uncertainty ( $U_{total}$ ) based on the uncertainties of the C stock change (CSC) and the area estimates.**

**2 SE means two times the standard error.**

| Code       | Land-use class                                    | Area                                        | CSC | $U_{total}$ | Area                                                | CSC | $U_{total}$ |
|------------|---------------------------------------------------|---------------------------------------------|-----|-------------|-----------------------------------------------------|-----|-------------|
|            |                                                   | Mineral soil (2 SE% or default uncertainty) |     |             | Drained organic soil (2 SE% or default uncertainty) |     |             |
| <b>4A1</b> | Forest land remaining forest land <sup>a</sup>    | 2                                           | 23  | 23          | 10                                                  | 25  | 27          |
| <b>4A2</b> | Cropland to forest land                           | 56                                          | 151 | 161         | 141                                                 | 25  | 143         |
| <b>4A2</b> | Intensive grassland to forest land                | 59                                          | 608 | 450         | NA                                                  | NA  | NA          |
| <b>4A2</b> | Settlements to forest land                        | 39                                          | 202 | 201         | NA                                                  | NA  | NA          |
| <b>4A2</b> | Unmanaged wetlands to forest land                 | NA                                          | NA  | NA          | 77                                                  | 25  | 81          |
| <b>4A2</b> | Managed wetlands to forest land                   | NA                                          | NA  | NA          | 72                                                  | 25  | 76          |
| <b>4B1</b> | Cropland remaining cropland                       | 7                                           | 50  | 50          | 24                                                  | 18  | 30          |
| <b>4B2</b> | Forest land to cropland                           | 44                                          | 151 | 157         | 141                                                 | 18  | 142         |
| <b>4B2</b> | Extensive grassland to cropland                   | 200                                         | 200 | 300         | NA                                                  | NA  | NA          |
| <b>4B2</b> | Intensive grassland to cropland                   | 107                                         | 200 | 224         | 200                                                 | 18  | 201         |
| <b>4B2</b> | Settlements to cropland                           | 141                                         | 373 | 450         | NA                                                  | NA  | NA          |
| <b>4B2</b> | Managed wetlands to cropland                      | NA                                          | NA  | NA          | 97                                                  | 18  | 99          |
| <b>4B2</b> | Unmanaged wetlands to cropland                    | NA                                          | NA  | NA          | 161                                                 | 18  | 162         |
| <b>4C1</b> | Intensive grassland remaining Intensive grassland | 13                                          | 91  | 92          | 78                                                  | 50  | 93          |
| <b>4C2</b> | Forest land to intensive grassland                | 33                                          | 608 | 450         | NA                                                  | NA  | NA          |
| <b>4C2</b> | Cropland to intensive grassland                   | NA                                          | NA  | NA          | 200                                                 | 50  | 201         |
| <b>4C2</b> | Unmanaged wetlands to intensive grassland         | NA                                          | NA  | NA          | 121                                                 | 50  | 131         |
| <b>4C2</b> | Settlement to Extensive Grassland                 | 200                                         | 189 | 300         | NA                                                  | NA  | NA          |

|            |                                                                      |     |     |     |     |    |     |
|------------|----------------------------------------------------------------------|-----|-----|-----|-----|----|-----|
| <b>4C2</b> | Settlement to Intensive Grassland                                    | 161 | 189 | 235 | NA  | NA | NA  |
| <b>4D1</b> | Managed wetlands - Peat extraction <sup>b</sup>                      | NA  | NA  | NA  | NA  | NA | 110 |
| <b>4D1</b> | Managed wetlands remaining managed wetlands (other drained wetlands) | NA  | NA  | NA  | 37  | 25 | 45  |
| <b>4D2</b> | Forest land to managed wetlands                                      | NA  | NA  | NA  | 200 | 25 | 201 |
| <b>4E1</b> | Settlement remaining settlement                                      | NA  | NA  | NA  | 55  | 22 | 59  |
| <b>4E2</b> | Cropland to settlements                                              | 45  | 373 | 450 | 100 | 22 | 102 |
| <b>4E2</b> | Forest land to settlements                                           | 19  | 202 | 201 | 72  | 22 | 75  |
| <b>4E2</b> | Extensive grassland to Settlements                                   | 99  | 189 | 212 | NA  | NA | NA  |
| <b>4E2</b> | Intensive grassland to Settlements                                   | 76  | 189 | 201 | NA  | NA | NA  |
| <b>4E2</b> | Unmanaged wetlands to settlements                                    | 139 | 200 | 235 | 136 | 22 | 138 |

<sup>a</sup> Uncertainty for mineral soil in forest remaining forest is combined for litter, dead wood, and mineral soil (see Table 6.3).

<sup>b</sup> The sub-category peat extraction includes on-site and off-site emissions; therefore, specific uncertainties for areas and CSC are not given.

For HWP, a default uncertainty of up to 50% (2 SE) is applied for activity data based on the IPCC 2013 KP Supplement (see section 6.10.2).

Default uncertainty estimates were also used for N<sub>2</sub>O and CH<sub>4</sub> emissions from drained organic soils, for direct and indirect N<sub>2</sub>O emissions, and biomass burning.

**Table 6.5 Uncertainties of N<sub>2</sub>O and CH<sub>4</sub> emissions for direct and indirect N<sub>2</sub>O emissions and for drained organic soils shown as total uncertainty (U<sub>total</sub>) based on the uncertainties of the emission factor (EF) and the activity data (AD).  
2 SE means two times the standard error.**

| Code         | Source                                          | Land-use class | Gas              | U <sub>total</sub>           | EF  | AD |
|--------------|-------------------------------------------------|----------------|------------------|------------------------------|-----|----|
|              |                                                 |                |                  | 2 SE% or default uncertainty |     |    |
| <b>4(I)</b>  | Direct N <sub>2</sub> O from inorganic N inputs | Forest land    | N <sub>2</sub> O | 201                          | 200 | 20 |
| <b>4(I)</b>  | Direct N <sub>2</sub> O from organic N inputs   | Settlements    | N <sub>2</sub> O | 201                          | 200 | 20 |
| <b>4(II)</b> | Drained organic soils                           | Forest land    | N <sub>2</sub> O | 120                          | 119 | 16 |

|               |                                              |                                    |                  |     |     |     |
|---------------|----------------------------------------------|------------------------------------|------------------|-----|-----|-----|
| <b>4(II)</b>  | Drained organic soils                        | Managed wetlands - Peat extraction | N <sub>2</sub> O | 151 | 113 | 100 |
| <b>4(II)</b>  | Drained organic soils                        | Other managed wetlands             | N <sub>2</sub> O | 124 | 119 | 36  |
| <b>4(II)</b>  | Drained organic soils                        | Settlements                        | N <sub>2</sub> O | 52  | 31  | 42  |
| <b>4(II)</b>  | Drained organic soils                        | Cropland                           | CH <sub>4</sub>  | 102 | 100 | 23  |
| <b>4(II)</b>  | Drained organic soils                        | Forest land                        | CH <sub>4</sub>  | 85  | 83  | 16  |
| <b>4(II)</b>  | Drained organic soils                        | Grassland                          | CH <sub>4</sub>  | 91  | 65  | 64  |
| <b>4(II)</b>  | Drained organic soils                        | Managed wetlands - Peat extraction | CH <sub>4</sub>  | 128 | NA  | NA  |
| <b>4(II)</b>  | Drained organic soils                        | Other managed wetlands             | CH <sub>4</sub>  | 85  | 77  | 36  |
| <b>4(II)</b>  | Drained organic soils                        | Settlements                        | CH <sub>4</sub>  | 61  | 44  | 42  |
| <b>4(III)</b> | Direct N <sub>2</sub> O                      | N mineralization/immobilization    | N <sub>2</sub> O | 224 | 200 | 100 |
| <b>4(IV)</b>  | Indirect N <sub>2</sub> O from managed soils | Atmospheric deposition             | N <sub>2</sub> O | 450 | 400 | 200 |
| <b>4(IV)</b>  | Indirect N <sub>2</sub> O from managed soils | Leaching and runoff                | N <sub>2</sub> O | 300 | 233 | 167 |
| <b>4(V)</b>   | Biomass burning                              | Wildfires in forest                | N <sub>2</sub> O | 75  | 70  | 28  |
| <b>4(V)</b>   | Biomass burning                              | Wildfires in forest                | CH <sub>4</sub>  | 75  | 70  | 28  |

In the cases where the uncertainty of the activity data estimate was not derived from the NFI, and the uncertainty of the CSC was based on expert judgment, the total uncertainty was derived by combining the two uncertainties. The specific methods and assumptions are described further for each of the sinks/sources under the sections of the individual land-use categories.

#### 6.1.4 Key categories

A sink or source can be a key category concerning the level (size of emission) or the trend (change in size between 1990 and 2021). Statistics Norway performs the key category analysis for the Norwegian inventory. All of the reported sinks and sources were included in the analysis for the LULUCF sector. The CSC estimates for living biomass, dead organic

matter (DOM), mineral soils, and organic soils were considered for each land-use conversion (e.g., forest land converted to cropland). The key category analysis was performed using Approach 1 and Approach 2 for the whole greenhouse gas inventory.

**Table 6.6 Approach 2 key category analysis results for the LULUCF sector showing level assessments for 1990 and 2021 and the trend assessment for 1990–2021.**

**Bold values indicate key categories; the larger the value, the more important the key category. In the Added/Removed category column, “A” stands for added and “R” for removed categories.**

| Code        | Sink/source category                                          | Gas              | Level assess 1990 | Level assess 2021 | Trend assess 1990–2021 | Added/ removed category |
|-------------|---------------------------------------------------------------|------------------|-------------------|-------------------|------------------------|-------------------------|
| 4.A.1       | Forest remaining forest - Living biomass                      | CO <sub>2</sub>  | <b>13.58</b>      | <b>15.08</b>      | <b>7.76</b>            |                         |
| 4.E.2.1.1   | Forest to Settlement – DOM                                    | CO <sub>2</sub>  | <b>9.64</b>       | <b>7.87</b>       | <b>0.71</b>            |                         |
| 4.A.1       | Forest remaining forest - Litter + dead wood + Mineral soil   | CO <sub>2</sub>  | <b>2.52</b>       | <b>6.03</b>       | <b>8.55</b>            |                         |
| 4.B.2.1     | Forest to Cropland - DOM                                      | CO <sub>2</sub>  | <b>1.49</b>       | <b>2.81</b>       | <b>3.40</b>            |                         |
| 4.C.2.1.in  | Forest to Intensive Grassland - DOM                           | CO <sub>2</sub>  | <b>0.47</b>       | <b>2.39</b>       | <b>4.38</b>            |                         |
| 4.C.2.1.in  | Forest to Intensive Grassland - Living biomass                | CO <sub>2</sub>  | <b>0.35</b>       | <b>2.39</b>       | <b>4.60</b>            |                         |
| 4.B.1       | Cropland remaining cropland - Organic soil                    | CO <sub>2</sub>  | <b>2.30</b>       | <b>2.27</b>       | <b>0.70</b>            |                         |
| 4.A.2.2.ex  | Extensive Grassland to Forest - Litter                        | CO <sub>2</sub>  | <b>0.50</b>       | <b>2.23</b>       | <b>3.96</b>            | A                       |
| 4.A.2.2.ex  | Extensive Grassland to Forest - DW                            | CO <sub>2</sub>  | <b>0.47</b>       | <b>1.62</b>       | <b>2.67</b>            |                         |
| 4.E.2.1.1   | Forest to Settlement - Living biomass                         | CO <sub>2</sub>  | <b>1.66</b>       | <b>1.56</b>       | <b>0.33</b>            |                         |
| 4.A.2.4     | Settlements to Forest – Litter                                | CO <sub>2</sub>  | <b>1.10</b>       | <b>1.54</b>       | <b>1.33</b>            | A                       |
| 4.A.1.i     | Forest remaining forest, drained organic soils - Organic soil | CO <sub>2</sub>  | <b>1.73</b>       | <b>1.51</b>       | 0.09                   |                         |
| 4.D.2.3.1   | Forest to Managed Wetland - DOM                               | CO <sub>2</sub>  | 0.00              | <b>0.86</b>       | 0.00                   | A                       |
| 4(II)Forest | Forest land - drained organic soils - Drained organic soil    | N <sub>2</sub> O | <b>0.95</b>       | <b>0.83</b>       | 0.05                   |                         |
| 4.A.2.4     | Settlement to Forest - DW                                     | CO <sub>2</sub>  | <b>0.62</b>       | <b>0.75</b>       | <b>0.50</b>            |                         |
| 4.E.2.1.1   | Forest to Settlement - Mineral soil                           | CO <sub>2</sub>  | <b>0.99</b>       | <b>0.64</b>       | <b>0.44</b>            |                         |
| 4.A.2.1     | Cropland to Forest - Litter                                   | CO <sub>2</sub>  | <b>0.68</b>       | <b>0.64</b>       | 0.14                   | A                       |
| 4.A.2.3.u   | Unmanaged Wetland to Forest - Litter                          | CO <sub>2</sub>  | 0.30              | <b>0.60</b>       | <b>0.76</b>            | A                       |
| 4.G         | Harvested wood Products - HWP                                 | CO <sub>2</sub>  | <b>2.63</b>       | <b>0.51</b>       | <b>3.78</b>            |                         |

|                   |                                                                    |                 |             |             |             |   |
|-------------------|--------------------------------------------------------------------|-----------------|-------------|-------------|-------------|---|
| <b>4.D.1.3.m</b>  | Managed Wetlands remaining managed wetlands - Organic soil         | CO <sub>2</sub> | <b>0.48</b> | <b>0.49</b> | 0.20        | A |
| <b>4.E.1.1</b>    | Settlements remaining settlements - Organic soil                   | CO <sub>2</sub> | 0.04        | <b>0.46</b> | <b>0.92</b> |   |
| <b>4(II)Crop</b>  | Cropland - drained organic soil - Organic soil CC + LC             | CH <sub>4</sub> | <b>0.51</b> | <b>0.46</b> | 0.08        |   |
| <b>4.A.2.2.in</b> | Intensive Grassland to Forest - Living biomass                     | CO <sub>2</sub> | 0.09        | <b>0.45</b> | <b>1.15</b> |   |
| <b>4.B.2.1</b>    | Forest to Cropland - Living biomass                                | CO <sub>2</sub> | 0.30        | <b>0.44</b> | <b>0.41</b> |   |
| <b>4.E.2.2.1</b>  | Cropland to Settlement -Mineral soil                               | CO <sub>2</sub> | <b>0.69</b> | <b>0.42</b> | <b>0.35</b> | A |
| <b>4.E.2.2.1</b>  | Cropland to Settlement -Organic soil                               | CO <sub>2</sub> | 0.00        | <b>0.39</b> | 0.00        | A |
| <b>4.A.2.2.in</b> | Intensive Grassland to Forest - DW                                 | CO <sub>2</sub> | <b>0.86</b> | <b>0.38</b> | <b>0.76</b> |   |
| <b>4.B.2.1</b>    | Forest to Cropland - Organic soil                                  | CO <sub>2</sub> | <b>0.57</b> | <b>0.38</b> | 0.22        |   |
| <b>4.A.2.1</b>    | Cropland to Forest - Living biomass                                | CO <sub>2</sub> | 0.26        | <b>0.38</b> | <b>0.35</b> |   |
| <b>4.A.2.1</b>    | Cropland to Forest - DW                                            | CO <sub>2</sub> | <b>0.47</b> | <b>0.37</b> | 0.06        |   |
| <b>4.A.2.3.u</b>  | Unmanaged Wetland to Forest - DW                                   | CO <sub>2</sub> | 0.24        | <b>0.34</b> | 0.30        |   |
| <b>4.E.2.1.1</b>  | Forest to Settlement - Organic soil                                | CO <sub>2</sub> | <b>0.53</b> | <b>0.32</b> | 0.28        |   |
| <b>4.D.1.1</b>    | Wetland Peat extraction - Organic soil                             | CO <sub>2</sub> | <b>0.41</b> | <b>0.32</b> | 0.06        | A |
| <b>4.D.2.3.1</b>  | Forest to Managed Wetland - Living Biomass                         | CO <sub>2</sub> | 0.00        | <b>0.32</b> | 0.00        | A |
| <b>4.C.1.in</b>   | Intensive Grassland remaining intensive grassland - Living biomass | CO <sub>2</sub> | <b>0.41</b> | 0.31        | 0.07        |   |
| <b>4.A.2.2.in</b> | Intensive Grassland to Forest - Litter                             | CO <sub>2</sub> | <b>1.62</b> | 0.30        | <b>2.36</b> | A |
| <b>4.C.1.in</b>   | Intensive Grassland remaining intensive grassland - Organic soil   | CO <sub>2</sub> | <b>0.45</b> | 0.30        | 0.18        | A |
| <b>4.B.2.3.u</b>  | Unmanaged Wetland to Cropland - Organic soil                       | CO <sub>2</sub> | <b>0.83</b> | 0.23        | <b>1.05</b> |   |
| <b>4.E.2.4.1</b>  | Unmanaged Wetland to settlements - Organic soil                    | CO <sub>2</sub> | 0.03        | 0.19        | <b>0.35</b> | A |
| <b>4.C.1.in</b>   | Intensive Grassland remaining intensive grassland - Mineral soil   | CO <sub>2</sub> | 0.14        | 0.12        | <b>0.52</b> |   |
| <b>4.A.2.3.u</b>  | Unmanaged Wetland to Forest - Living biomass                       | CO <sub>2</sub> | 0.18        | 0.05        | <b>0.44</b> |   |
| <b>4.C.1.ex</b>   | Extensive grassland remaining extensive grassland - living biomass | CO <sub>2</sub> |             |             |             | R |

From the analyses, 41 key categories were identified by Approach 2 level and trend assessments. 13 key categories were added, and 1 key category was removed (see Table 6.6).

### 6.1.5 Completeness

The following sources were not reported because they are not mandatory (see table in chapter 1.7 of this document):

- C stock change in living biomass, DOM, and net C stock change in soils on flooded land remaining flooded land (CRF Table 4.D.1.2) and
- CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> emissions from rewetting of organic soils on forest land, cropland, grassland, and wetlands (CRF Table 4(II)).

Furthermore, the following sources were not reported because emissions are considered negligible: non-CO<sub>2</sub> emissions from controlled burning on forest land and from wildfires on grasslands (CRF Table 4(V)), and emissions (CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>) on land converted to peat extraction (CRF Table 4.D.2.1).

For the emissions considered negligible, an assessment was made of the approximate and likely emissions given limited data sources to see if they qualify as non-significant. The assessment is based on three criteria i) emission must be less than 0.05% of non-LULUCF emissions (CO<sub>2</sub> eq), ii) emissions must be less than 500 kt CO<sub>2</sub> eq yr<sup>-1</sup> and iii) emissions reported as NE must not together exceed 0.1% of the national non-LULUCF emissions. The first two criteria are considered in section 6.15.1.5 for controlled forest fires and grassland wildfires and in section 6.7.3 for lands converted to peat extraction. The third (aggregate) criterion is considered below. The notation key NE is used in the CRF tables for sources that were not reported.

#### 6.1.5.1 Aggregate of non-significant emissions

The third criterion for the qualification as non-significant is that emissions reported as NE must not together exceed 0.1% of the national non-LULUCF emissions. Three sources were reported as NE:

- controlled forest fires (non-CO<sub>2</sub>),
- grassland wildfires (non-CO<sub>2</sub>),
- lands converted to Peatland Extraction (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O)



For grassland wildfires, the areas were unknown prior to 2016. For testing for the significance, the time series for grassland wildfires was estimated in two ways:

- 1) using the mean of 2016-2019 for all years and
- 2) using the mean of 2016-2019 for all years, except individual years 2016 – 2019, in which the annual areas were used.

See section 6.15.1.5 for controlled forest fires and grassland wildfires and section 6.7.3 for lands converted to peat extraction.

The likely aggregated emissions of all three sources reported as NE (for grassland wildfires, mean annual emissions were used) ranged from 11 – 15 kt CO<sub>2</sub> eq yr<sup>-1</sup> and were less than 0.1% of the non-LULUCF emissions (0.02-0.03%). If only data available for individual years is used for grassland wildfire, the likely aggregated emissions for all three NE sources ranged from 10 – 17 kt CO<sub>2</sub> eq yr<sup>-1</sup> and were less than 0.1% of the non-LULUCF emissions (0.02-0.03%). With the above and in addition information in sections 6.7.3 and 6.15.1.5, we conclude that NE emissions qualify as non-significant.

#### **6.1.6 Quality assurance and quality control (QA/QC) for LULUCF**

NIBIO implements the QA/QC plan described for the National Inventory System in Annex V. In addition, a LULUCF-specific plan for QA/QC was developed internally at NIBIO. The LULUCF-specific plan has two objectives: (1) to ensure that emission estimates and data contributing to the inventory are of high quality and (2) to facilitate an inventory assessment regarding quality and completeness. These objectives follow IPCC 2006 Guidelines, Vol. 1, Ch. 6, for quality assurance and control.

The QA/QC plan for the LULUCF sector is based on the general Tier 1 QC procedures and includes

- a check list (for ensuring that key quality checks are conducted by source-category and LULUCF inventory compiler, see Annex V),
- an annual schedule of the outlined QC activities,
- a target to elicit QA reviews when a methodology is being implemented/revised (see below).

Several QA projects have been undertaken for the LULUCF reporting. Generally, QA is initiated if a new method or model is implemented. Below are some examples of previously elicited QA activities.

Two external quality-assurance actions were undertaken in 2012. First, elicitation by the Norwegian Institute for Forest and Landscape (now NIBIO) of a qualified researcher was performed to evaluate and improve the methodologies applied for emission estimates from cropland and grassland. This work resulted in substantial method revisions for most source categories due to the lack of methods evaluation since their development was documented by (Rypdal et al. 2005). Moreover, detailed documentation and justification of the new methods are provided in the report *Emissions and methodologies for cropland and grassland used in the Norwegian national greenhouse gas inventory* (Borgen & Hylen 2013). The second external QA was a smaller task performed on the final emission estimates for mineral soil on grassland remaining grassland, which was elicited from an expert at Colorado State University. This task provided a review of the emission calculations (the new Tier 1 method application) and the method and activity data documentation. The methods were developed in accordance with the IPCC 2006 Guidelines and implemented in the National GHG inventory in 2013.

Work was done to QA the Yasso07 model estimates for mineral soil on forest land in 2014 - 2015. In this project, modelled and measured soil C stocks were compared on two field sites over time. Results from these sites and the overall estimation methodology for the relevant pools on forest land were discussed at two seminars with three contracted external experts from Finland, Denmark, and Norway (Dalsgaard et al. 2017). In addition, Yasso07 (current methodology) and field estimates of soil C stocks were compared (Dalsgaard et al. 2016b).

With the implementation of the IPCC 2006 Guidelines, an external QA was elicited on the HWP calculations. The QA was performed by an expert from the Swedish University of Agricultural Sciences before the NIR 2015 submission.

An external QA was performed on the updated Tier 1 methodology to estimate changes in soil organic carbon after land-use change on mineral soils (Bárcena et al. 2021) in 2020 - 2021 by a LULUCF expert from the Stockholm Environment Institute (Estonia). A soil expert at the Norwegian University of Life Sciences was involved in developing the methodology. The methodology was implemented in NIR 2021.

The QC is performed on the following 12 points:

- Documentation of assumptions and selection criteria
- Transcription errors
- Area and emission calculations
- Labelling of parameter units, conversion factors, and unit transfers

- Database integrity
- Consistency within sectors and source categories
- Transfer of estimated emissions between inventory staff
- Uncertainty estimation and calculations
- Review of internal documentation
- Time-series consistency
- Completeness
- Comparison to previous estimates

Logical tests are carried out through different stages in the data processing and transcription routines to meet many of the QC points mentioned above. Such tests include consistency in land representation, emission, stock change factors, CRF table transcriptions, etc. A detailed list of specific tests is stored locally.

The National Forest Inventory (NFI) has its own set of QA/QC routines related to field work and registration (see section 6.3.8).

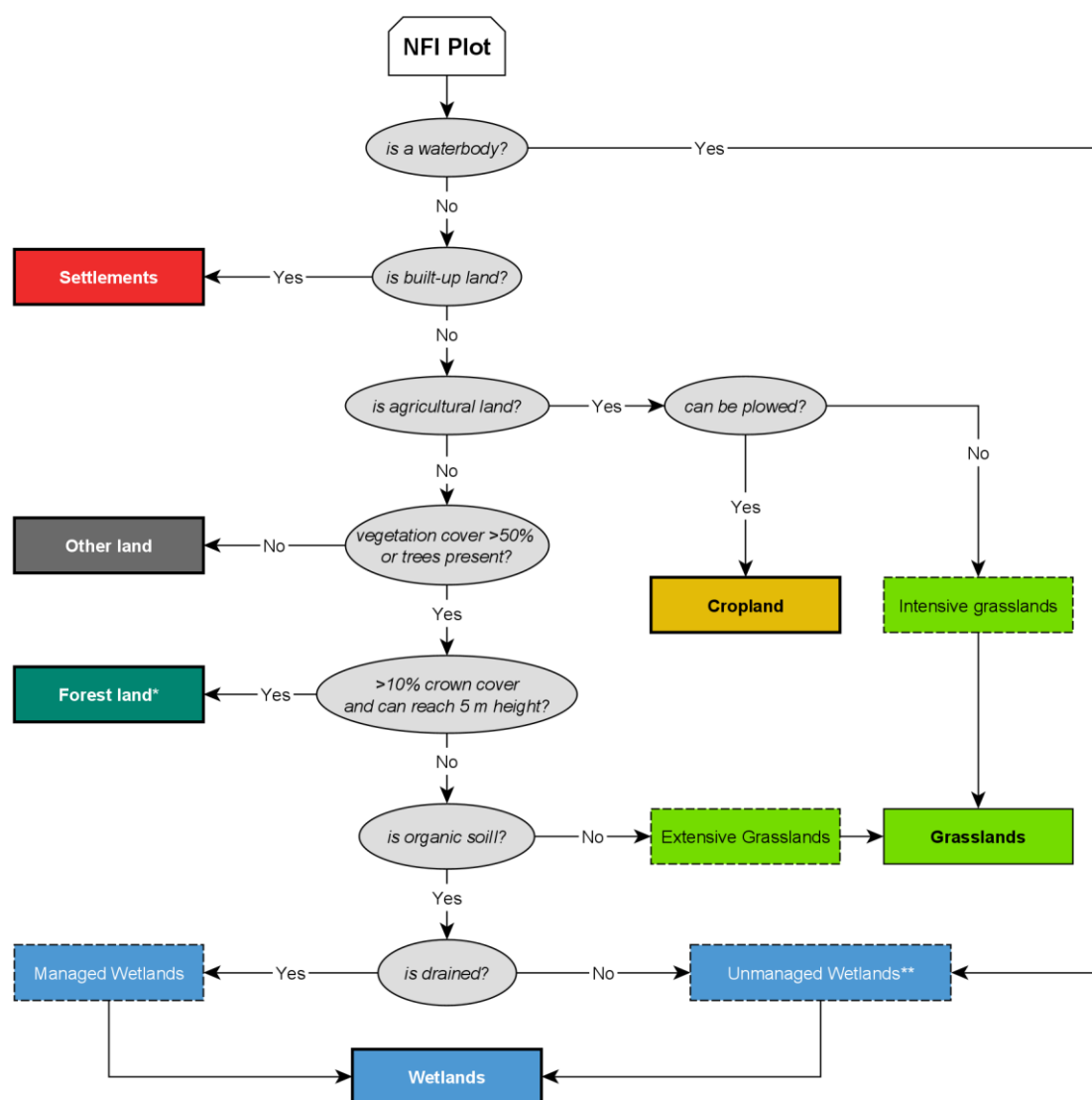
The CRF tables went through internal QC by more than one person before the database was submitted to the national focal point. Furthermore, after the overall compilation of estimates from all sectors, CRF tables were exchanged from the focal point to NIBIO, and an additional QC was performed. Two independent experts carried out the area estimates using two different statistical software systems based on the same database. Improving the QA/QC procedures is an ongoing process that will be further improved in future submissions.

## 6.2 Land-use definitions and classification system

### 6.2.1 Land-use definitions

National Forest Inventory (NFI) data are used to estimate the total area of forest land, cropland, grassland, wetlands, settlements, other land, and the land-use transitions between these. The NFI is used as activity data for all land-use categories because it covers the whole country by sample plots. In addition, the NFI is the most reliable data set available that can be used to determine transitions between different land-use categories during the whole reporting period in a consistent manner. The land-use categories are defined following the IPCC 2006 Guidelines. They are described below, using national terminology.

For a unit of land to be classified as separate from an adjacent land-use category, it must have a minimum area and width of 0.1 ha and 4 m, respectively, which is consistent among all land-use categories in Norway. The NFI land cover and land-use categories and their transcription into IPCC land-use categories are illustrated in Table 6.7. All forest land, cropland, grassland, and settlement are managed lands. The vast majority of wetlands and all of other land are unmanaged. Wetlands areas with direct human impact are considered managed. Because managed and unmanaged lands are reported for the specific categories, total unmanaged lands are reported as IE (CRF Table 4.1).



*Figure 6-7: Decision tree for land-use classification. An area will remain in a land-use category until it meets the criteria for another land-use category (e.g., cropland areas will remain in the cropland category even though abandoned as long as they do not meet the forest definition or otherwise change land use). \*Forest land classification rule exception: Forest land will remain forest land even if it is temporarily below <10% tree crown cover due to harvest or natural disturbances. A land where trees are planted for forest production will be classified as forest land even though they are temporarily below the <10% tree crown cover criteria. \*\*Flooded lands (managed) are not currently included in the national inventory, and as such, all waterbodies, regardless of management status, are reported under unmanaged wetlands.*

According to the IPCC 2006 Guidelines, managed land is land where human interventions and practices have been applied to perform production, ecological or social functions. Norway defines managed lands relative to unmanaged lands as follows:

- Croplands and Settlements are subject to clear human influence and thus are considered managed in their totality.
- Forest lands and Grasslands - Humans have inhabited and influenced the landscapes in Norway for thousands of years. There are long traditions of utilizing both forested and open lands for grazing and other resource use, influencing carbon stocks. Therefore, the Forest lands and Grasslands in Norway are also considered managed in their totality.
- Wetlands consist of both water bodies and land which is water saturated during all or most of the year (mires). The vast majority of Wetlands areas are considered unmanaged. Any grazing that may occur here is assumed not to influence carbon stocks significantly. However, wetland areas with direct human impact are considered managed. These are peatland extraction areas and mires with ditches. Further, water reservoirs built in connection with power-stations are managed. However, Norway does not report on flooded lands (no methodology currently exists for estimating emissions), as these areas are currently not separated from natural water bodies and are thus reported as unmanaged.
- Other lands are areas with no significant carbon stocks (bare soil, rock, ice), and human activities will thus not influence carbon stocks. These areas are considered unmanaged in their totality.

**Table 6.7 NFI land cover and land-usage categories and their correspondence to the UNFCCC land-use categories. Empty cells indicate land usage and land cover combinations that do not exist**

| Land<br>usage<br>Land<br>cover                               | Forestry,<br>or no<br>specific<br>land<br>usage | City, urban<br>area<br>Settlements<br>of different<br>kinds | Cabin<br>area (5)     | Recreation<br>area    | Military<br>training<br>field | Protected<br>Area,<br>Nature<br>Reserve | Roads/Railroad<br>Airport | Power<br>line (6)     | Other                 |
|--------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------------------|-----------------------|-----------------------|-------------------------------|-----------------------------------------|---------------------------|-----------------------|-----------------------|
| <b>Productive forest (1)</b>                                 | Forest land                                     | Settlements                                                 | Forest land           | Forest land           | Forest land                   | Forest land                             | Settlements               | Settlements           | Settlements           |
| <b>Non-productive forest (2)</b>                             | Forest land                                     | Settlements                                                 | Forest land           | Forest land           | Forest land                   | Forest land                             | Settlements               | Settlements           | Settlements           |
| <b>Other wooded land with crown cover 5-10% (3)</b>          | Grassland (extensive)                           | Settlements                                                 | Grassland (extensive) | Grassland (extensive) | Grassland (extensive)         | Grassland (extensive)                   | Settlements               | Settlements           | Settlements           |
| <b>Other non-wooded areas (4)</b>                            | Grassland (extensive)                           | Settlements                                                 | Grassland (extensive) | Grassland (extensive) | Grassland (extensive)         | Grassland (extensive)                   | Settlements               | Grassland (extensive) | Grassland (extensive) |
| <b>Wooded mire, crown cover 5-10%</b>                        | Wetlands                                        | Settlements                                                 | Wetlands              | Wetlands              | Wetlands                      | Wetlands                                | Settlements               | Settlements           | Settlements           |
| <b>Coastal heath</b>                                         | Grassland (extensive)                           | Settlements                                                 | Grassland (extensive) | Grassland (extensive) | Grassland (extensive)         | Grassland (extensive)                   | Settlements               | Grassland (extensive) | Settlements           |
| <b>Bare rocks &amp; glaciers</b>                             | Other land                                      | Settlements                                                 | Other land            | Other land            | Other land                    | Other land                              | Settlements               |                       | Settlements           |
| <b>Non-wooded mire</b>                                       | Wetlands                                        |                                                             | Wetlands              | Wetlands              | Wetlands                      | Wetlands                                | Settlements               |                       | Wetlands              |
| <b>Lakes and rivers (not sea)</b>                            |                                                 | Wetlands                                                    |                       | Wetlands              | Wetlands                      | Wetlands                                | Wetlands                  |                       | Wetlands              |
| <b>Closed pasture grazing land, not regularly cultivated</b> |                                                 |                                                             |                       |                       |                               | Grassland (intensive)                   |                           |                       | Grassland (intensive) |
| <b>Arable land, regularly cultivated</b>                     |                                                 |                                                             |                       |                       |                               | Cropland                                |                           |                       | Cropland              |
| <b>Other areas (4)</b>                                       | Settlements                                     | Settlements                                                 |                       | Settlements           | Settlements                   | Settlements                             | Settlements               | Settlements           | Settlements           |

- 1) *Productive forested area is defined as a forest with crown cover that exceeds 10% and with a potential yield of stemwood, including bark of  $> 1 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ .*
- 2) *Non-productive forested area is defined as a forest with crown cover that exceeds 10% and with a potential yield of stemwood, including bark of  $< 1 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ .*
- 3) *Other wooded land is defined as land with sparse tree cover with crown cover between 5 and 10% and hosts trees that have the potential to reach a height of 5m or with a combined cover of shrubs, bushes, and trees above 10%. It is classified as other wooded land when found on mineral soil (organic layer  $< 40 \text{ cm}$  deep) and as wooded mire, if found on organic soil (organic layer  $> 40 \text{ cm}$  deep).*
- 4) *Land on mineral soil with no trees, or less than 5% crown cover, or less than 10% crown cover if a combination of shrubs, bushes, and trees.*
- 4) *Gravel pits, mines, gardens, halting places, skiing slopes, forest roads, etc.*
- 5) *Excluding the area covered by cabins themselves, including a 5 m buffer classified as settlements.*
- 6) *Only recorded for tree-covered land usage categories affected by different management under power lines.*

**Forest land (4A)** is defined in the National Forest Inventory (NFI). The values used in the NFI are in accordance with the range of parameters in the definition from the Global Forest Resources Assessment 2005 (FAO 2006). Forest land is land with tree crown cover  $> 10\%$ . The trees must be able to reach a minimum height of 5 m at maturity in situ. The minimum area and width for forest land in the Norwegian inventory is 0.1 ha and 4 m. Forest roads are considered settlements. The minimum area and width are consistent among all land-use categories in Norway. Young natural stands and all plantations established for forestry purposes, as well as forest land, which is temporarily unstocked due to, e.g., harvest or natural disturbance, are included under forest land. All forest in Norway is managed either for wood harvesting, protection and protective purposes, recreation, and/or to a greater or lesser extent, hunting and berry picking. On more marginal and less productive forest land, the various management practices may be less intense but still be present. Hence, all forest in Norway is considered managed.

**Cropland (4B)** is part of agricultural land. It is defined as annually cropped lands, regularly cultivated, and ploughed. Both annual and perennial crops are grown. It also encompasses grass leys in rotations with annual crops, which may include temporarily grazed fields regularly cultivated. This category includes arable land that was previously annually cropped and regularly ploughed but has since been abandoned. These areas remain in the cropland category until they have regrowth of trees that make them unsuitable for ploughing. All cropland is considered managed.

**Grassland (4C)** is defined in two sub-categories:

- (1) Intensive grassland is part of agricultural land. The areas are utilized for grazing on an annual basis. Over 50% of the area is covered with grass, which may be partly covered with trees, bushes, stumps, rocks etc. The grass may be mechanically harvested, but the soil

cannot be ploughed. An area will be classified as intensive grassland even though it meets the forest definition (> 10% crown cover) if grazing is the dominant land-use.

(2) Extensive grasslands are areas on mineral soil with significant C stock that do not fall into any of the other five land-use categories, such as heath and other wooded lands (i.e., land with sparse tree cover) and open areas with ground vegetation. Most of these areas are outfield grazing areas and are grazed to some extent.

All grassland is considered managed.

**Wetlands (4D)** are defined as lakes, rivers, mires, and other areas regularly covered or saturated by water for at least part of the year. Trees may stock mires, but with a tree coverage that does not meet the forest definition. All waterbodies are reported as having mineral soil, while mires are reported as having organic soil. Most wetlands are assumed to be unmanaged. Wetlands areas with direct human impact are considered managed. These are peatland extraction areas and mires with ditches. Further, water reservoirs built in connection with power-stations are managed. However, as these areas are currently not separated from natural water bodies, they are reported as unmanaged.

**Settlements (4E)** include all types of built-up land: houses, gardens, villages, towns, cities, parks, roads, railways, golf courses, sport recreation areas, power lines within forests, areas close to cabins (< 5m), industrial areas, gravel pits, and mines. All settlements are considered managed.

**Other land (4F)** is defined as areas without significant C pools, such as bare soil, rocks, and ice, that do not fall into the other five land-use categories. Other land is considered unmanaged.

| Table 6.8 Management status of different land-use categories. An area is only classified as belonging to one land-use category.<br>The predominant national land cover and land use determine the assigned category. |                                    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| Land-use category                                                                                                                                                                                                    | Management status                  |
| Forest land                                                                                                                                                                                                          | Managed                            |
| Cropland                                                                                                                                                                                                             | Managed                            |
| Grassland                                                                                                                                                                                                            | Managed                            |
| Wetlands                                                                                                                                                                                                             | Unmanaged and managed (small area) |
| Settlements                                                                                                                                                                                                          | Managed                            |
| Other land                                                                                                                                                                                                           | Unmanaged                          |



## 6.2.2 Consistency in areas and reporting categories

### 6.2.2.1 Area consistency

Until the 2010 submission, the area of the different land-use categories was based on sample plots below the growth limit of coniferous trees. To determine the land use at higher elevations and in Finnmark county, the NFI included the first complete set of sample plots for these areas from 2005 - 2010. That allows for assessment of the extent of forest area, other wooded land, and other land uses in these areas. The plots are incorporated into the ordinary management plan for the NFI. On plots without previous measurements, land use and biomass development were estimated back to 1990 (backcasting) using data from the NFI, maps and aerial photographs for settlements, grassland, and cropland. That was done to improve the area estimates from 1990 for all new plots included in the system.

The definitions of land cover and land-usage categories have been consistent for most categories since the permanent plots were established in 1986 - 1993. There have, however, been some changes in definitions throughout this period that have affected the land-use change matrix. The most important change relates to the forest definition. In 2005, the NFI forest definition was adjusted to the definition of forest land (IPCC 2003), replacing a similar but not identical definition. The change in the forest definition did not result in an inconsistency in the time series because the new definition was also applied to NFI data acquired before 2005. Also, the category grassland had not been defined in the land-use classification in the first cycle of the NFI with permanent sample plots (6<sup>th</sup> NFI, 1986 - 1993). The land-use classes assessed in the 7<sup>th</sup> NFI (1994 - 1998) have been utilized for the corresponding plots in the 6<sup>th</sup> NFI. The Norwegian Mapping Authority provided the value for the total land area of Norway.

### 6.2.2.2 Land subject to multiple land-use change

A few plots undergo multiple land-use change transitions within the 20-year period. Such plots create issues applying the 20-year transition rule and constructing the land-use change matrix (Table 6.2). The technical implementation of plot-wise compared to panel-wise (aggregation of multiple plots) interpolation and extrapolation for area estimates (see section 6.3.5) is that it allows for each transition to be tracked yearly for the whole time series. The tracking then allows the possibility to capture which plots have undergone more than one land-use change and for which transitions the 20-year conversion rule should be applied to.



|                                         |  |  |  |  |  |  |  |  |  |
|-----------------------------------------|--|--|--|--|--|--|--|--|--|
| Arable land,<br>regularly<br>cultivated |  |  |  |  |  |  |  |  |  |
|-----------------------------------------|--|--|--|--|--|--|--|--|--|

*Litter:* For forest land remaining forest land, the changes (model generated) in the dead organic matter pool are the changes resulting from the modelled input and decomposition of all dead organic material (woody and non-woody, aboveground and belowground; C input) regardless of size and stage of decomposition. Only the most recalcitrant material (humus) originating from root decomposition is allocated to the soil pool. The changes in the litter and the dead wood pools, respectively, are allocated according to the origin of the model C input (aboveground or belowground elements), the chemical quality and the size of the C input elements – see details in section 6.4.1. For land converted to or from forest land, the litter pool entails the default carbon stocks, as presented in the IPCC 2019 Refinement for the ecological zones and forest types, which are most representative of the conditions found in Norway, as determined by expert judgment. Fine woody litter (dimension 1-7.5 cm) is included as a part of the litter pool using external data, as such data is unavailable for Norway. Changes in the litter pool are computed (instant oxidation or accumulation over a specific length of time) according to the IPCC 2006 Guidelines.

*Dead wood:* For forest land remaining forest land, the estimates for carbon stock changes in the dead wood pool are modelled (see above for *litter*). For land converted to or from forest land, the dead wood pool entails the default carbon stocks presented in the IPCC 2019 Refinement for the ecological zones and forest types relevant to Norway. Changes in the dead wood pool are computed (instant oxidation or accumulation over a specific length of time) according to the IPCC 2006 Guidelines.

*Mineral and organic soils:* Because soil mapping was historically covered by three entities (mapping schemes), separating organic and mineral soils differs somewhat between forest land, cropland, and grassland. On forest land, wetland and other wooded land, organic soils mapping was performed by the NFI and was defined as having an organic layer deeper than 40 cm with no requirement on minimum C content. On cropland and intensive grasslands, organic soils were partially mapped by a national soil survey (The Norwegian agricultural soil classification database). They were defined as organic when classified as Histosols, according to WRB. So far, the soil survey covers only 59% of all croplands and 8% of all intensive grasslands. The remaining non-covered area for cropland (41%) and intensive grasslands (92%) classification were derived from the national land resource map

AR5<sup>29</sup> based on old economic maps where organic soils were defined by a topsoil organic layer deeper than 20 cm (cropped land) or 30 cm with no requirement on minimum carbon content. Mineral soil types are areas not considered as either organic soils or barren lands (see above under “other lands”). For forest land remaining forest land, the estimates for carbon stock changes in the soil pool (mineral soil) are modelled (see above for *litter*). For land converted to or from forest land, the soil pool (mineral soil) entails the default carbon stocks as presented in the IPCC 2019 Refinement for the IPCC stratification zones relevant for Norway with changes computed according to the IPCC 2006 Guidelines.

As strict correspondence with the official organic soil definition of the World Reference Base (WRB 2015) would be impossible (Table 6.10), the general term “organic soil” used consistently throughout this report refers to the three definitions mentioned above.

**Table 6.10 Organic soil definition for the three entities that participated in the Norway carbon mapping compared with WRB definition.**

| Entities                    | Land use covered                           | Topsoil organic horizon |                                                      |
|-----------------------------|--------------------------------------------|-------------------------|------------------------------------------------------|
|                             |                                            | Thickness               | C content%                                           |
| <b>NFI</b>                  | Forest, other wooded land and wooded mires | ≥ 40cm                  | -                                                    |
| <b>National soil survey</b> | 59% cropland<br>8% intensive grassland     | ≥ 40 cm                 | ≥ 10%                                                |
| <b>AR5</b>                  | 41% cropland<br>92% intensive grassland    | ≥ 20 cm                 | -                                                    |
| <b>WRB (Histosol)</b>       | All                                        | ≥ 10cm                  | Rare saturation: >20% in top 20 cm*                  |
|                             |                                            |                         | Frequent saturation, clay = 0%: ≥12% in top 20 cm*   |
|                             |                                            |                         | Frequent saturation, clay > 60%: ≥18% in top 20 cm * |

\*The top 20 cm may partially include the mineral horizon if the organic layer thickness < 20 cm.

## 6.3 Land area representation and the National Forest Inventory

The area representation applied in the LULUCF reporting is based on the Norwegian National Forest Inventory (NFI). Land accounting is based on Approach 3 according to IPCC 2006 Guidelines. Under the convention reporting, we apply a 20-year transition period.

<sup>29</sup>[http://kilden.skogoglandskap.no/?topic=arealinformasjon&layers=ar5\\_bonitet&X=7260874.41&Y=125323.37&zoom=0&lang=nb&bgLayer=gratone\\_cache&layers\\_opacity=0.75](http://kilden.skogoglandskap.no/?topic=arealinformasjon&layers=ar5_bonitet&X=7260874.41&Y=125323.37&zoom=0&lang=nb&bgLayer=gratone_cache&layers_opacity=0.75)

Hence, land stays in a conversion class for 20 years (transition period) before transferring it to a remaining class.

### 6.3.1 Current NFI design

The NFI can be characterized as a single-phase, permanent, systematic, and stratified survey (Breidenbach et al. 2020). An interpenetrating panel design is used, where 1/5<sup>th</sup> of the sample plots evenly distributed throughout the country (the so-called “panel”) using a Latin square design are measured yearly. The Norwegian Institute of Bioeconomy Research (NIBIO) operates the NFI. Inventory work was started in 1919 with regular inventory cycles. The 12<sup>th</sup> inventory cycle started in 2020 and will be completed in 2024.

The NFI divides Norway into four strata: lowlands (below the coniferous limit) except Finnmark county, mountain areas (above the coniferous limit) except Finnmark, lowlands in Finnmark, and mountain areas in Finnmark. The lowland strata contain the most productive forests, while the forests in the other strata consist mainly of low-productive birch forests. The NFI does not consider the arctic island groups Svalbard and Jan Mayen.

NFI sample plots are placed on the intersections of grid lines to ensure a systematic distribution of the plots (Figure 6-8). The distance between neighbouring plots is different between the different strata. A 3x3 km (Easting x Northing) grid is used in the lowlands, including Finnmark county, a 3x9 km grid is used in the mountains not located in Finnmark, and a 9x9 km grid is used in the mountainous area of Finnmark county (Figure 6-9).

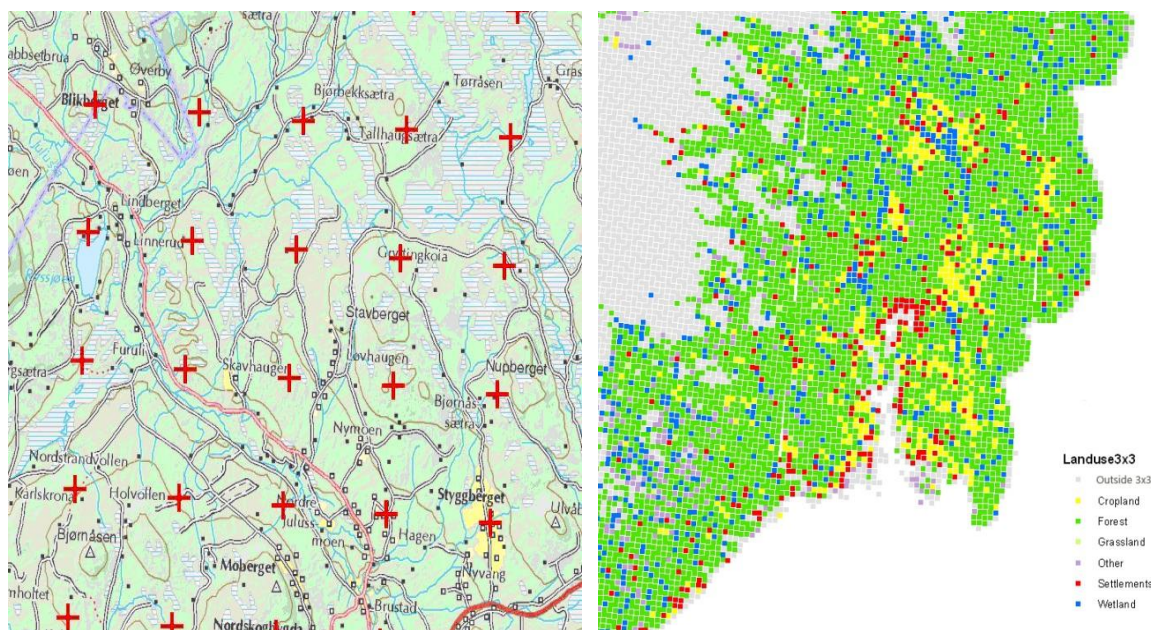
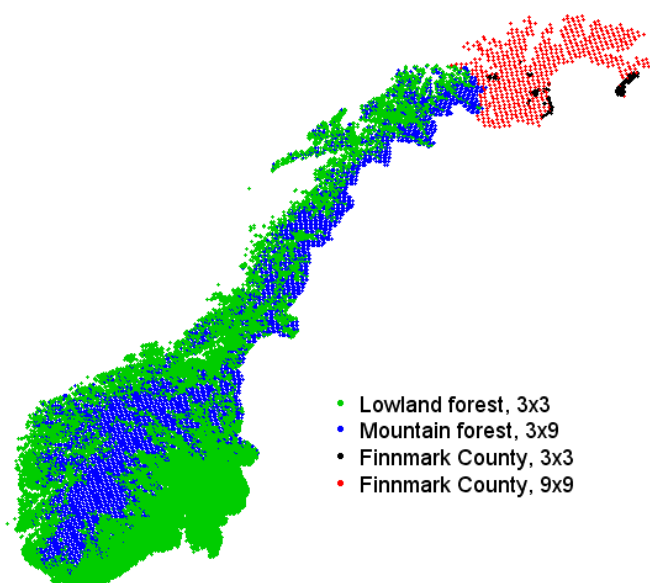


Figure 6-8 The sample plots cover all land-use categories. Plots are placed in the systematic 3x3 km grid in the example map to the left. On the right-hand side, we see the distribution of land use-categories in the south eastern part of Norway below the coniferous tree line (only 3x3 grid).



*Figure 6-9 Spatial distribution (approximate locations) of the NFI sample plots in the four strata. The sample plots in Finnmark county located on the 3x3 km grid cover lowlands, while the sample plots on the 9x9 km grid cover mountainous areas.*

As can be seen from the estimate of all land-use categories for 2010, more than 94% of the tree living biomass stock is allocated in the lowland forests outside Finnmark (Table 6.11). The mountain forest outside Finnmark, the mountain forest in Finnmark county, and the lowlands in Finnmark account for 3.7%, 1.6%, and 0.4% of the carbon in tree living biomass, respectively.

**Table 6.11 Area and estimates of C stocks in living biomass in 2010 (the reference year is based on observations from 2008 – 2012) by stratum and associated uncertainties.**  
SE = standard error

| Stratum                                 | Area (kha) | C stock (kt) | 2 SE (%) C stock | Percent (%) of total C stock |
|-----------------------------------------|------------|--------------|------------------|------------------------------|
| <b>Lowlands outside Finnmark</b>        | 14 989     | 423 533      | 2.9              | 94.3                         |
| <b>Mountain forest outside Finnmark</b> | 12 528     | 16 738       | 12.3             | 3.7                          |
| <b>Lowlands in Finnmark</b>             | 135        | 1 773        | 21.4             | 0.4                          |
| <b>Mountain forest in Finnmark</b>      | 4 727      | 7 164        | 24.9             | 1.6                          |
| <b>All</b>                              | 32 378     | 449 208      | 2.9              | 100.0                        |

A plot that has measured trees in the current inventory is always revisited in the next inventory. Plots not visited in the field in the most recent inventory are monitored using aerial images acquired approximately every five years for the entire country. From the aerial images, the plot is assessed for land-use changes and the occurrence of trees. If it is not possible to determine the land-use category with certainty or if there is an indication that the sample plot may be tree covered, the sample plot is visited in the field. Exceptions are cropland and settlements, which are not visited in the field to measure tree parameters.

Among other attributes, the positions, diameter at breast height (DBH, diameter measured at 1.3 m above ground) and tree species of all trees with DBH  $\geq$  50 mm are recorded on circular sample plots with a radius of 8.92 m (250 m<sup>2</sup>). All tree heights are measured using hypsometers on plots with 10 trees or fewer. On plots with more than 10 trees, heights are measured on a relascope-selected subsample with a target sample size of 10 trees per plot (NFI 2008). The heights of the unmeasured trees are estimated using tariffs (models) calibrated at the plot-level with data from measured trees (Breidenbach et al. 2014).



The area of a stratum  $A_h$  area is estimated by multiplying the proportion of points on the 3x3 km grid that belong to the stratum  $h$  with Norway's land area. The representation factor, also known as the design weight or the inverse of the sampling probability, determines how much area of Norway one sample plot represents. The representation factor of a sample plot is given by  $A_h/n_h$ , where  $n_h$  is the number of sample plots on the grid specific to the stratum.

If a sample plot covers two land-use classes, the sample plot, and consequently also the representation factor, are divided between the plot parts according to the proportion of the land-use classes covering the plots. A land-use class must cover at least 20% of the sample plot to be considered. Land-use class cover is recorded in 10% steps on divided sample plots.

### 6.3.2 Land stratification to climate

The land area is stratified into IPCC climate regions using nationally available climate data (see below). Norway implements climate-region-dependent Tier 1 methodologies, which are applied spatially-explicit.

Each of these methodologies is applied spatially explicitly (Approach 3), where each NFI plot is designated to a climate region. The IPCC 2006 Guidelines, Vol 4. Ch. 3, Figure 3A.5.2, provides climate classification schemes for determining the climate region based on criteria for mean annual temperature (MAT), mean monthly temperature (MMT), mean annual precipitation (MAP), potential evapotranspiration (PET), and elevation. Applying these criteria to the 30-year mean (1989 – 2018) of the annual values provides Norway with the six climate regions presented in Table 6.12.

| <b>Table 6.12 Area representation of Norway's IPCC climate regions based on NFI plots.</b> |                            |            |
|--------------------------------------------------------------------------------------------|----------------------------|------------|
| <b>IPCC climate region</b>                                                                 | <b>Area representation</b> |            |
|                                                                                            | <b>(kha)</b>               | <b>(%)</b> |
| <b>Boreal Dry</b>                                                                          | 862                        | 2.66       |
| <b>Boreal Moist</b>                                                                        | 4805                       | 14.84      |
| <b>Cool Temperate Dry</b>                                                                  | 273                        | 0.84       |
| <b>Cool Temperate Moist</b>                                                                | 22432                      | 69.28      |
| <b>Polar Dry</b>                                                                           | 5                          | 0.02       |
| <b>Polar Moist</b>                                                                         | 4001                       | 12.36      |
| <b>Total</b>                                                                               | 32378                      | 100.00     |



The IPCC climate regions for NFI plots with forest land can be further stratified into ecological zones. The ecological zone classification scheme provided by the Forest Resources Assessment<sup>30</sup> (FAO) uses the same variables to define IPCC climate regions but has slightly different and additional criteria. The ecological zones combined with the IPCC climate regions, along with additional information on dominant tree stand type, are used to derive IPCC default carbon stock estimates for litter and dead wood for land-use changes to and from forest land described in section 6.4.2 (Bárcena et al. 2021).

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<sup>30</sup> [FAO FRA workingpaper179 2015 GlobalEcologicalZones ap861e00.pdf](#)

### Box 1 - The climate data

The source of the meteorological datasets used to produce the climate data for NFI plots is known as SeNorge. SeNorge is a collaboration between The Norwegian Water Resources and Energy Directorate (NVE), The Norwegian Meteorological Institute, and The Norwegian Mapping Authority, which provide climate, meteorological, and hydrological data, respectively, for Norway. The SeNorge data is available to the general public through the web portal [senorge.no](https://senorge.no). Full access to all the dataset products (intended for research) are available partially through ftp thread-servers (temperature and precipitation) or through contact with NVE (hydrological data).

The datasets consist of daily values on a 1 x 1 km UTM zone 33 projection grid over Norway. Daily mean (TG) and daily total precipitation (RR) can be found as part of the SeNorge\_2018 dataset (Lussana et al. 2019). The daily time series, for the current published dataset is from 01/01/1957 to 31/12/2019, with the latest year being updated periodically. These datasets are aggregated to the required monthly and annual values. Furthermore, the temperature from the 1 x 1 km grid cell is adjusted (downscaled) for the elevation acquired from a high-resolution 10 x 10 m digital terrain model (DTM, provided by The Norwegian Mapping Authority), with a lapse rate of -0.65°C per 100 meters of altitude (Tveito & Førland 1999).

Daily evapotranspiration on a 1 x 1 km grid was provided by NVE. The evapotranspiration is modelled using the gridded water balance model (GWB) and a spatially distributed version of the hydrological model HBV. As the name suggests, the model accounts for water balance within a catchment, by calibrating parameters used in the transfer rate of hydrological processes (Engeland et al. 2004). The daily temperature and precipitation from SeNorge1.1 are used as input data for the model.

The daily evapotranspiration calculated by the GWB model is considered here to be the actual evapotranspiration (AET), given that it accounts for the availability of soil moisture, unlike potential evapotranspiration (PET), which represents the maximum possible evapotranspiration when there is no limit to the availability of water. PET is not available from the SeNorge datasets. It was therefore calculated using the Thornthwaite method; an empirical model in which mean monthly temperature and mean monthly daylight (hours) are used as input (Thornthwaite 1948). Daylight hours are calculated using a solar calculator function from the R-package StreamMetabolism (Sefick 2016) based on the NOAA Solar Calculator (National Oceanic and Atmospheric Administration 2020) adjusted (downscaled) for the elevation acquired from a high-resolution 10 x 10 m digital terrain model (DTM, provided by The Norwegian Mapping Authority), with a lapse rate of -0.65°C per 100 meters of altitude (Tveito & Førland 1999). The PET estimates were replaced by AET estimates for the instances where AET exceeded PET.

### 6.3.3 Land stratification to soil classes

To identify the overall soil type (mineral or organic) for all land-use classes, additional sources to the NFI data are necessary for all sample plots without tree cover. One additional data source is The Norwegian agricultural soil classification database, which contains soil survey data from the ongoing field survey, and which currently holds information on 59% of croplands and 8% of intensive grasslands. Another additional data source on the overall soil type for the rest of the land area was derived from the national land resource map AR5<sup>31</sup>. A “baseline 1990 map” was created from these two datasets in which the land area is classified to mineral or organic soil, covering cropland, grassland, and settlement. The overall soil type information on forest land and wetlands was derived from NFI registrations. The combinations (overlay with NFI plot positions) of data sources enabled geo-referencing of the areas of organic soils for each land-use class and tracking of land-use changes on mineral or organic soils. The map was updated in 2021.

For NFI plots on mineral soil, soil categorization is further detailed by soil class. Soil class is determined from digital versions of two legacy soil maps from Rasmussen et al. (1991) and Låg (1983), respectively, and updated with modern data from The Norwegian agricultural soil classification where possible (Bárcena et al. 2021).

The mineral soil classes are used in combination with the IPCC climate regions to derive soil organic carbon reference values from both the IPCC 2006 Guidelines and the IPCC 2019 Refinement, as described in the Tier 1 methodology for the estimation of changes in soil organic carbon after land-use change on mineral soil (Bárcena et al. 2021).

Figure 6-10 displays Norway's land uses and stratification by overall soil type, IPCC climate region, and FAO ecological zones.

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<sup>31</sup>[http://kilden.skogoglandskap.no/?topic=arealinformasjon&layers=ar5\\_bonitet&X=7260874.41&Y=125323.37&zom=0&lang=nb&bgLayer=gratone\\_cache&layers\\_opacity=0.75](http://kilden.skogoglandskap.no/?topic=arealinformasjon&layers=ar5_bonitet&X=7260874.41&Y=125323.37&zom=0&lang=nb&bgLayer=gratone_cache&layers_opacity=0.75)

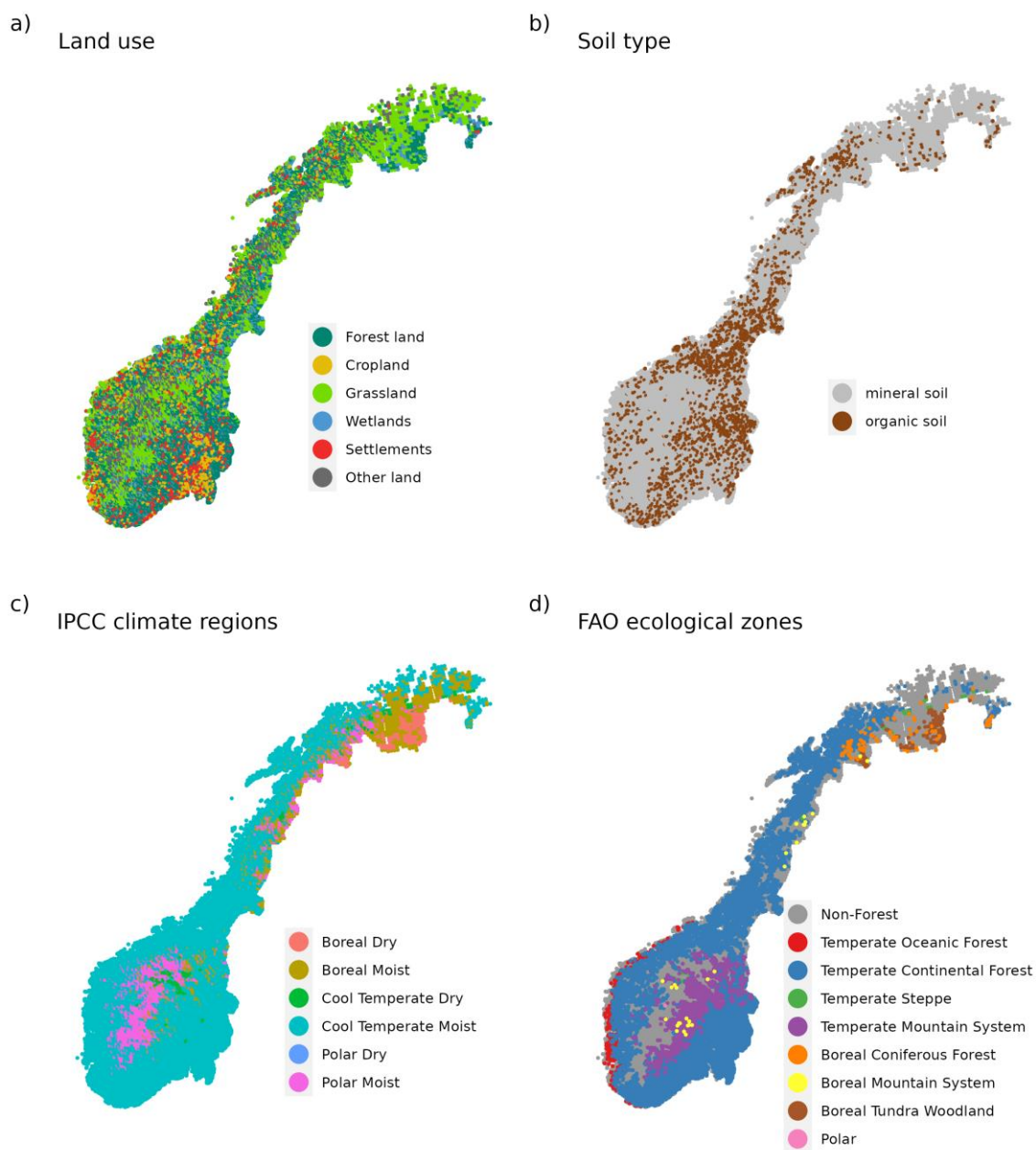


Figure 6-10 Map overview of NFI plot stratification:

a) Land use categories as of 2005 to 2021; b) soil types; c) IPCC climate regions; d) FAO ecological zones for forest lands. The visual representation of each plot on the maps is altered to ensure the visibility of all categories, as the plotting order affects the visibility.

### 6.3.4 Changes in the NFI design

The NFI consisted of temporary sample plots before 1986.

#### 6.3.4.1 *Panels and plot size of the earliest permanent inventories*

Between 1986 and 1993, all lowland sample plots outside Finnmark were permanently marked. All sample plots within one to three neighbouring counties were measured within one year. Annual estimates representative of the whole country were therefore complicated in those years. The current system with interpenetrating panels was made fully operational in the cycle covering the years 1994 through 1998.

Today, all sample plots are circular with a size of 250 m<sup>2</sup>. However, in the inventory period between 1986 and 1993, concentric sample plots were used in some counties. All trees with a DBH  $\geq$  50 mm were measured on a circular sample plot with an area of 100 m<sup>2</sup>. Trees with a DBH larger than 19.9 cm were measured on a larger sample plot. The area of the large sample plots was 200 m<sup>2</sup> in Østfold, Akershus, Oslo, and Nord-Trøndelag counties, whereas the area was 250 m<sup>2</sup> in all other counties. The sample weights of the trees on these plots were modified to bridge the methodological change in the subsequent inventory period, where all sample plots had a size of 250 m<sup>2</sup>.

#### 6.3.4.2 *Establishing the NFI strata in Finnmark and the mountain areas outside Finnmark*

The sample plots in the mountain stratum outside Finnmark were established between 2005 and 2009. The first re-measurements of these plots were consequently started in 2010. The sample plots in the two Finnmark strata were established between 2005 and 2011, with the first re-measurements starting in 2012. This made special methods for estimating changes on the plot-level necessary, as described in section 6.2.2. However, almost 95% of the C stock in tree living biomass is found in the lowland stratum outside Finnmark. The land use classes observed on the plots in Finnmark and the mountain plots established between 2005 - 2009 (2005 - 2011 for Finnmark) were backcasted to 1990 for each plot. Plots were assigned to one of the two Finnmark strata in the inventory cycle by assessing their location on the 3x3 km grid. In a number of western and northern Norwegian municipalities outside Finnmark, a height threshold separating lowland and mountain areas was set by local forest authorities. In the other parts of Norway, the stratum decision was made using auxiliary information and in the field. The strata classification can therefore be described as a two-phase procedure.

#### **6.3.4.3 *Changes in tree height measurement methods and land use classification from those in early inventories***

Prior to 2005, the tree heights of three trees per species were measured on each sample plot. Since 2005, 10 trees per plot have been measured as described above.

Until 1994 no differentiation between grasslands and croplands was made; both were considered agricultural land. Since 1994, this difference has been made, and the areas of croplands and grasslands were backcasted.

#### **6.3.4.4 *Limited information available during the establishment of mountain plots***

No aerial photos were available in the first two years of establishing the mountain plots outside Finnmark (2005 and 2006). Maps (N50) were used to determine which plots could be forested. Those were visited in the field, while the remaining plots were given a land use class derived from an overlay of the maps (plot centre). A plot with a centre in a land use class was assumed to be that land use class on its full area (circle of 250 m<sup>2</sup>). If the plot centre was in the water, the sample plot was not visited, even if it was close to a forest. Between 2010 and 2011, all plots were checked against aerial images. Land use changes occurred to and from all land use classes. Most commonly, however, parts of the plots in water were then considered other land or wetland (mire), but in some cases, forest, or other land use classes. The changed land use class and possible measurements of trees were backcasted to 1990 in those cases.

#### **6.3.4.5 *More detail in registrations included for land-use classes other than forest***

Until 2005, trees were not measured on land-use classes other than forest. Sample plots were only split if one of the parts was a forest. In other cases, the plots were categorized as fully covering the land-use class of the centre coordinate. After that, tree measurements have also been included in other land-use classes than forest. From 2005 part of the land use categories extensive grassland and wetlands with 5 - 10% crown cover (areas defined as Other wooded land and Wooded mire, see Table 6.7) were included in the area with tree measurement. From 2007 trees have been measured on all land-use categories except cropland and settlements, and since 2010 also trees below power lines (part of the settlements category) have been measured. This resulted in splitting a number of sample plots between other land use classes than forest, which resulted in area changes of those land use classes. The changed land use class and possible measurements of trees were backcasted to 1990 in those cases.

#### **6.3.4.6 *Change of forest definition in 2005***

The forest definition was changed to be in accordance with the FAO definition in 2005 to include crown cover. Until 2005, the forest definition was based on the potential productivity of the land, which had to be greater than or equal to 0.1 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> to be

considered a forest. Since 2005, the crown cover on a 0.1 ha area centred on the plot has to be greater than 10% to be forest land. After harvests, areas may be temporarily unstocked but remain forest in the NFI classification system unless the land use changes later. For young productive forests, the stem number is also considered. All plots meeting the new definition of forest visited for the first time in the NFI period 2005 - 2009 (2005 - 2011 for Finnmark) were backcasted. All plots (not only new plots) meeting the new definition of forest were also considered forests in 1990. Plots with human-induced afforestation were exceptions. Exceptions were also made in productive forests if the plot had been assessed as “non-forest” in a previous cycle and the tree ages clearly allowed determining a year of change from another land-use class to forest.

### 6.3.5 Inter- and extrapolation for the area and living biomass estimates

The NFI consists of five panels, each of which consists of approximately 1/5<sup>th</sup> of all 22 008 sample plots. Panel #1 was installed<sup>32</sup> in 1994, and the other panels in the following years, such that panel #5 was installed in 1998. After the panels were installed, all plots were re-measured every 5 years. However, all sample plots were visited for the first time and permanently marked between 1986 and 1993. Before the current panels were installed, the measurement intervals for the sample plots within a panel varied. For example, for panel #1 in 1994, the sample plots were previously measured between one and eight years before.

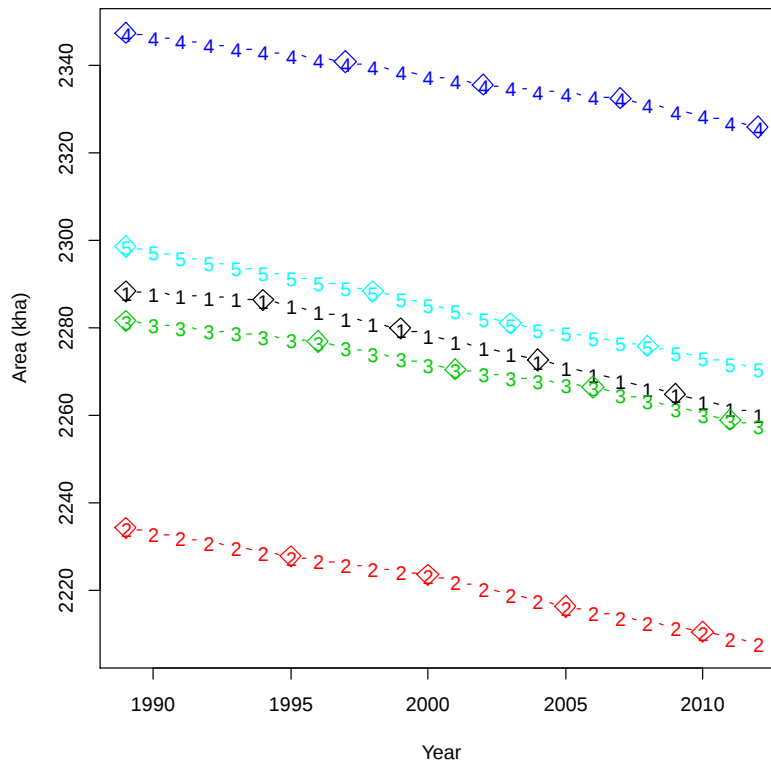
All estimates are based on linear interpolation of areas and C stocks between plot-wise observations that are then aggregated to the panel and national levels. The first estimate for each panel is for 1989, based on sample plots measured between 1986 and 1993 in the respective panel. Towards the end of the reporting period, estimates were extrapolated based on the last two estimates per plot. This way, the rate of land-use changes is projected based on observations of the last 10 years (Figure 6-11). The extrapolation results in recalculations of estimates of the last four years in the forthcoming reports as new data become available. Once new data becomes available, interpolation can be used instead of extrapolation.

An example to illustrate the method: while no extrapolation was necessary for panel #4 in the 2014 reporting (2012 as the final year), four years of extrapolation were necessary for panel #5 (Figure 6-11). Measurements on panel #5 for 2013 became available in the 2015 reporting (2013 as the final year), which resulted in a recalculation of the years 2009 - 2012 for panel #5.

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<sup>32</sup> Installation in this context means that all sample plots within the panel were visited in one year. All sample plots (in the lowlands outside Finnmark) were visited and marked for the first time between 1986 and 1993.

The annual estimate for a source/sink reported is the sum of all plot estimates for that source/sink for a given panel measured in the reporting year and the interpolated or extrapolated estimates of the other panels in the reporting year.



*Figure 6-11 Estimated forest land remaining forest land area covering mineral soils within the five NFI panels illustrated with data from 1989 until 2012. Diamonds indicate the measurement year of the sample plots in the respective panel (1 – 5). The estimated area was the sum of interpolated plots between two measurement years and extrapolated in the years after the last measurement year in each panel. Areas of land converted to forest land that will change their category to forest land remaining forest land after 2009 are not considered in the graphic.*

More formally, the area of a land-use class ( $A_{LUC}$ ) in a given measurement year (diamonds in Figure 6-11) is the sum over all  $i=1, \dots, n_P$  sample plots within a panel

$$A_{LUC} = \sum_i p_{LUC,i} \cdot rf_i$$

where  $p_{LUC,i}$  is the proportion (0,...,1) of a land-use class covering a sample plot, and  $rf$  is the representation factor (the area of Norway which the sample plot represents).



Linear interpolation of stocks means constant changes (gains and losses) between two measurements. Biomass losses (fellings) are mainly due to harvests and are observed over five years in each panel. In order to reflect the annual variability in harvests, the constantly interpolated or extrapolated biomass losses have been adjusted according to harvest statistics provided by Statistics Norway (Figure 6-12). This results in annual variability of the net carbon changes. The adjustment according to the harvest statistics was carried out for the land-use categories of land converted to forest land and forest land remaining forest land.

The change of biomass stocks (gains or losses) within a land-use class in a given measurement year (diamonds in Figure 6-12) is the sum of changes over all sample plots within a panel

$$c_{LUC} = \sum_i p_{LUC,i} r_{f_i} c_{LUC,i}$$

where  $c_{LUC,i}$  is the mean annual change of the biomass stock per hectare on a sample plot per land-use class. The change  $c_{LUC,i}$  can either be a gain (positive change) or a loss (negative change) of biomass. Net gains and losses can simultaneously occur in a sample plot. Biomass gains or losses were multiplied with the default factor of 0.5 to obtain estimates of carbon gains or losses.

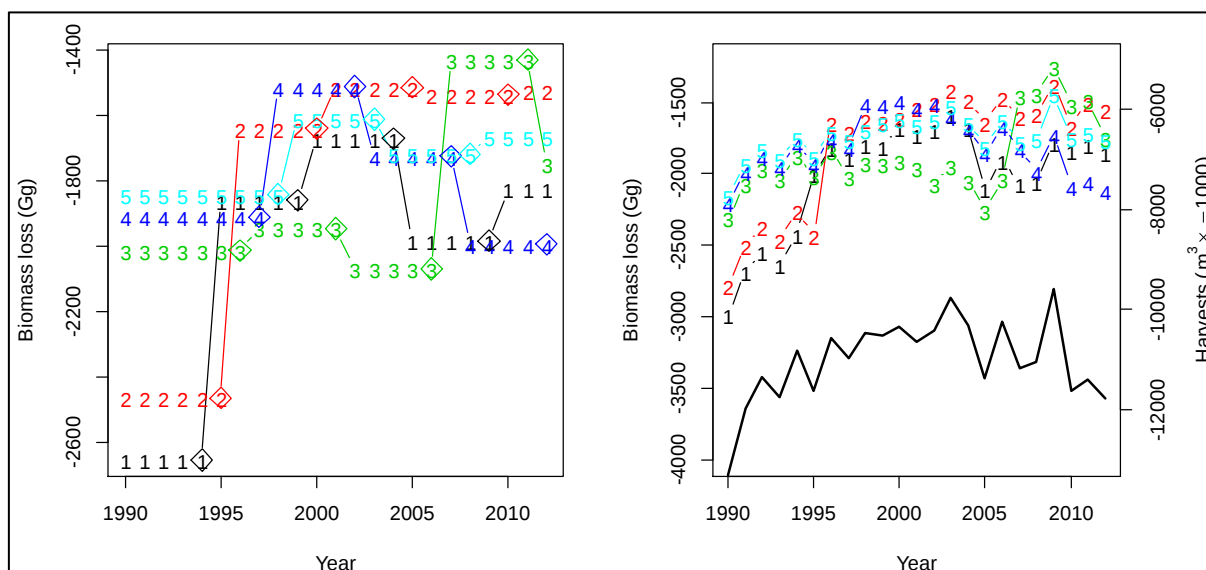


Figure 6-12 Biomass losses in forest land remaining forest land observed on the five panels illustrated with data from 1989 until 2012. Left-hand side: Diamonds indicate the measurement year of the sample plots in the respective panel. The estimated biomass loss was interpolated between two measurement years and extrapolated in the years after the last measurement year in each panel. Interpolation and extrapolation are based on a constant function. Right-hand side: The constant interpolation or extrapolation is adjusted according to harvest statistics (thick black line).

The harvest statistics are based on Tables 06964 and 03795 (Statistics Norway 2023a), describing the timber use by assortment and municipality. This table was supplemented by the estimated use of domestic firewood obtained from Table 11181 (Statistics Norway 2023b) and Trond Amund Steinset - Statistics Norway (Personal communication, 2020).

### 6.3.6 Backcasting correction of area and estimates

All estimates were made from 1990 to the current year, with all land-use areas starting in the remaining category in 1989. However, many of these areas would have been in a state of land-use change because of changes before 1990. Given the land use transition period (D) of 20 years, many of these areas would still be in transition until as late as 2009. To address this issue, an area correction methodology is applied to all areas and their emissions from 1990 to 2009.

Area correction is only applied to area estimates derived from the NFI. The correction is done by first calculating mean land-use change rates from 1994 to 2003<sup>33</sup> without applying the 20-year transition rule for all converted land categories. Areas for mineral and organic soil are processed separately. The land-use change rates are then used to predict the area in different land uses in 1969 under the constraint that all areas were in a remaining land-use category in 1969. The land-use change rates are then used to predict areas in land use transition forward from 1969 with the 20-year transition rule applied for lands in conversion. The first land-use changes occurring in 1970 will remain in a land-use change category until 1989, with a transition to the remaining category in 1990. Following this method for consecutive years, 1971 land-use changes will transition into the remaining category in 1991, 1972 land-use changes will transition into the remaining category in 1992, et cetera. This approach thereby ensures an area correction until 2009. From 2010 to the current year, the backcasting land-use change rates are no longer applicable, and the backcasting correction is not applied.

The general method to correct the net emissions/removals estimates is to apply the implied emission factor (IEF) to the new corrected area for each year. Temporal mean IEF's are based on data from 1990 to the current year and applied for the whole period where backcasting correction is relevant. This procedure is applied to both mineral and drained organic soil emissions. For lands converted to forest land, CSC for litter and dead wood are estimated based on the corrected total area for each land-use change (see section 6.4.2).

In the case of tree living biomass on forest land, no correction is needed for the total estimates, as these are based on actual measurements on the forest land plots, irrespective of whether the plots are land converted to forest land (LF) or forest land remaining forest land (FF). However, because there is an underestimation of area converted to forest land due to the lack of information providing the correct land-use change designation prior to 1990 (i.e., we only know what forest land was in 1989, not how much is FF or LF), a redistribution of the living biomass between LF and FF is required. This is done similarly to the general method, where the IEF is first combined with the new corrected area. Second, the new estimates of CSC in living biomass are used to calculate the living biomass fraction for LFs and FF relative to each other. These fractions are then multiplied with the original estimate of total CSC in tree living biomass on forest land (FF+LF).

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<sup>33</sup> The goal is to capture the national LUC rates closest to the year 1989. However, the NFI does not start with the regular 5-year cycle until 1994 (see 6.3.5). 1994 - 2003 (10 years) therefore provides the two NFI cycles closest to 1989.

No correction is applied for DOM or living biomass for transitions from forest land to other land-use categories, as instantaneous oxidation is assumed for the initial year in transition. Similarly, gains and losses in the grass and annual crop biomass for transitions to and from grassland and croplands, respectively, occur instantaneously within the first year of land-use change observation. Hence, no backcasting correction is needed<sup>34</sup>. Table 6.13 presents the total LULUCF GHG emissions before and after the applied backcasting correction. From 1990 to 2009, the amount of correction declines as less and less pre-1990 land-use changes transfer into the remaining categories with increasing years in the time series.

**Table 6.13 Total LULUCF GHG emissions (kt CO<sub>2</sub> equivalents) before and after backcasting correction.**

| Year | After correction | Before correction | diff.  | %   |
|------|------------------|-------------------|--------|-----|
| 1990 | -11967.7         | -11694.3          | -273.4 | 2.3 |
| 1991 | -13762.9         | -13503.9          | -259.0 | 1.9 |
| 1992 | -13160.7         | -12916.2          | -244.6 | 1.9 |
| 1993 | -14701.4         | -14471.2          | -230.2 | 1.6 |
| 1994 | -12596.0         | -12380.3          | -215.7 | 1.7 |
| 1995 | -16886.0         | -16684.9          | -201.0 | 1.2 |
| 1996 | -15931.6         | -15745.2          | -186.4 | 1.2 |
| 1997 | -14504.0         | -14332.0          | -172.0 | 1.2 |
| 1998 | -16683.7         | -16526.8          | -156.9 | 0.9 |
| 1999 | -18058.4         | -17916.1          | -142.3 | 0.8 |
| 2000 | -19588.3         | -19460.5          | -127.9 | 0.7 |
| 2001 | -21488.2         | -21375.0          | -113.2 | 0.5 |
| 2002 | -22547.2         | -22448.7          | -98.5  | 0.4 |
| 2003 | -24121.1         | -24037.4          | -83.7  | 0.3 |
| 2004 | -23758.9         | -23689.9          | -69.0  | 0.3 |
| 2005 | -21032.3         | -20978.1          | -54.2  | 0.3 |
| 2006 | -22971.8         | -22932.4          | -39.4  | 0.2 |
| 2007 | -23057.3         | -23032.6          | -24.7  | 0.1 |
| 2008 | -24338.3         | -24328.5          | -9.8   | 0.0 |
| 2009 | -27697.6         | -27702.6          | 5.0    | 0.0 |

<sup>34</sup> Because the exact year of land-use change is unknown (it is only known that it happened during the last 5 years before the observation), interpolation will evenly distribute the instant gains or losses over the time interval between the current and previous point in time (usually 5-years).

### 6.3.7 Uncertainties in areas and living biomass

Standard errors of area and biomass change estimates used in the key category analysis were estimated based on a 5-year moving average estimate for the mid-year of the last NFI cycle. For example, in NIR 2018, the last NFI cycle includes measurements from 2012 – 2016, which means that the mid-year was 2014. Model-related uncertainties resulting from interpolation and extrapolation are ignored. Also, model-related uncertainties resulting from using biomass models to estimate single tree biomass from diameter and height measurements were ignored since they can be assumed to be small for CSC compared to the sampling error (Breidenbach et al. 2014). Furthermore, the uncertainty from using an estimated instead of measured tree height for some trees on the sample plots was ignored. Also, this source of variation can be assumed to be negligible compared to that of sampling. In addition, the variance estimators are conservative (slightly overestimate the uncertainty) because they assume a simple random sample (SRS), whereas the NFI collects a systematic sample (Magnussen et al. 2020).

The estimated proportion of a land-use class within a stratum is given by

$$p_h = 1/n_h \sum_i y_{hi}$$

where  $h = (1, \dots, 4)$  is the stratum identifier,  $n$  is the number of sample plots,  $y$  is the proportion of the NFI sample plot that belongs to a land-use class, which is 1 if the sample plot falls completely into the class, and  $i = 1, \dots, n_h$ .

The estimated variance of the proportion is given by

$$\text{var}(p_h) = \frac{s_h^2}{n_h}$$

with  $s_h^2 = \frac{1}{n_h - 1} \sum_i (y_{hi} - \bar{y}_{hi})^2$ . The area estimate of a land-use class ( $A_{LUC}$ ) over all strata is then given by the stratified estimator

$$A_{LUC} = A \frac{1}{N} \sum_h N_h p_h$$

where  $A$  is Norway's land area,  $N$  is the land area divided by the NFI plot size,  $N_h$  is the stratum area divided by the plot size, and  $p_h$  is the proportion of the respective land-use class. The estimated variance of the area estimate is given by

$$\text{var}(A_{LUC}) = A \sum_h \left( \frac{N_h}{N} \right)^2 \text{var}(p_h).$$

Similar to the area estimates, estimates of sampling errors of carbon gains or losses are based on the full set of NFI sample plots. The ratio estimator gives the estimate of the total biomass gain or loss within a stratum

$$T_h = \frac{N_h}{n_h} \sum_{i=1}^{n_h} y_{hi}$$

where  $n_h$  is the number of sample plots within a stratum and  $y$  is the average annual gain or loss that occurred during the last five years on a sample plot. An estimate of the variance is given by

$$\text{var}(T_h) = N_h^2 \frac{s_h^2}{n_h}.$$

The total biomass gain or loss estimate (T) over all strata and its variance (var(T)) is the sum over  $T_h$  and  $\text{var}(T_h)$ , respectively. Because random sampling is assumed, the variance estimates can be assumed to be conservative.

Post-stratification did not improve the precision of biomass gain and loss estimates. We tested climatic zones, counties, and forest districts as possible post-strata.

The estimation of biomass or C stocks is not required in the CRF. This report calculated stocks in analogy to the biomass change estimates.

The uncertainties of carbon estimates are given by

$$U(C) = \sqrt{U(T)^2 + U(CF)^2}$$

where  $U(T)$  is the uncertainty of the total biomass gain or loss estimate in percent of the estimate

$U(T) = \frac{2\sqrt{\text{var}(T)}}{T} 100$  and  $U(CF)=2\%$  is the relative uncertainty in the carbon fraction.

### 6.3.8 QA/QC for the NFI data

Fieldwork is conducted by NFI field staff. Qualification requirements are forestry or natural management education at the college level or higher. Before a new employee can work independently, a training period of at least three weeks is conducted. All field staff undergo a weeklong course prior to each field season. There are currently about 25 employees who perform fieldwork in the period from May to October. It has been a stable situation with few changes in the field personnel, and on average, the field workers have more than 15 years of experience.

All data is collected on handheld computers with software developed for the purpose. The field computer program has a number of features built in for quality assurance:

- The program ensures that everything that must be recorded is recorded.
- A series of tests on the logical values of measurements.
- Categorical variables are recorded with the help of menus.

The field computer contains data from the previous record for plots where previous inventories are registered. Depending on the character of the variable, quality checks are handled in three different ways:

- The old value is displayed and can be confirmed or amended.

- The old value is hidden, but a warning is given if the new value is not logically compared to the old value.
- The old value is displayed as information before a new registration is done.

Data is sent by e-mail to the data reception centre at the main office once a week. The data reception centre keeps track of which sample plots have been registered and which plots remain, thereby ensuring that no plots are omitted. The data is then read into a database, and further quality checks are made. Incorrect data or questions are returned to the field worker for clarification.

Each field worker is usually visited by a supervisor for one day in the field. Control registrations are carried out by an experienced field worker who makes a second registration for approximately 5% of all sample plots. The control data is then analyzed to document the quality of field recordings, partly to clarify misunderstandings and correct any systematic errors. The results of control entries are published in a separate report. During the winter months, there is a systematic data review with additional error testing and inspection of all codes and logic. This happens before the data is read into the final table structure.

The database is a relational database that is designed to ensure data quality. Primary keys and foreign keys prevent double accounting and ensure coherence in the data.

## 6.4 Forest land – 4A

### 6.4.1 Forest land remaining forest land, 4A1

Forest land remaining forest land covers slightly more than 12 million hectares (ha). Forest ownership in Norway is dominated by private ownership, with many small properties. In 2021 there were 124 551 forest holdings with more than 2.5 ha of productive forest land in Norway (Statistics Norway 2023c). Due to the ownership structure and specific terrain conditions, Norwegian forestry is diversified and characterized by small-scale activity. The average size of clear-cuttings was estimated to be 1.9 ha in 2003 (Statistics Norway 2004). Approximately 90% of the harvesting is fully mechanized.

Forest land is the most important land-use category concerning biomass sequestration in Norway. According to the Approach 2 key category analysis (Section 6.1.4), forest land is a key category for sequestration in tree living biomass, dead wood, litter, and mineral soils, and emissions from drained organic soils in both levels and trend.

### 6.4.1.1 Methodological issues

#### 6.4.1.1.1 Living biomass (key category)

The sink/source category living biomass is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

The stock change method is used. The method implemented corresponds to Tier 3, which uses a combination of NFI data and models to estimate changes in biomass.

The reported C stock change (CSC) refers to the biomass of all living trees observed on an NFI sample plot with a stem diameter larger than 50 mm at breast height (DBH). Thus, shrubs and non-woody vegetation are not included in the estimates. Since tree coordinates are measured on NFI plots, each tree can be attributed to a land use category. Single tree allometric regression models developed by Smith et al. (2016; 2014), Marklund (1988), and Petersson and Ståhl (2006) are applied to DBH and height measurements from the NFI for estimating the tree biomass. For consistency with estimates reported under the Kyoto Protocol, tree biomass is defined as the sum of aboveground and belowground biomass. The aboveground biomass of a tree is the sum of the estimates of the fractions of stem, stump, bark, living branches, and dead branches. The belowground biomass of a tree is the estimate of the fraction of stump and roots minus the estimate of the fraction of stump. Table 6.14 lists the models used to estimate the biomass of the different tree fractions. The biomass models are defined for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and birch (*Betula pendula* and *Betula pubescens*). These species constitute approximately 91% of the growing stock volume (Svensson et al. 2021). Other broad-leaved species constitute most of the remaining proportion. The birch biomass models are applied to all broad-leaved species. The tree living biomass is estimated consistently based on the same biomass models from the base year 1990 onwards.

**Table 6.14 Biomass models for estimating living biomass.**

**In Marklund's (1988) models, the notation "G (model number)" indicates Norway spruce and "T (model number)" Scots pine.**

| Component               | Reference and specific model                                                                            |
|-------------------------|---------------------------------------------------------------------------------------------------------|
| Dead branches           | Marklund (1988), G20, T22. Smith et al. (2014) birch/deciduous                                          |
| Living branches         | Marklund (1988), G12, T14, Smith et al. (2014) birch/deciduous, includes needles                        |
| Foliage                 | Smith et al. (2014) birch/deciduous                                                                     |
| Bark                    | Marklund (1988), G8, T10. Smith et al. (2014) birch/deciduous                                           |
| Stem                    | Marklund (1988), G5, T6. Smith et al. (2014) birch/deciduous                                            |
| Stump                   | Marklund (1988), G26, T28                                                                               |
| Stump and roots (>2 mm) | Petersson and Ståhl (2006), B i (for Norway spruce and Scots pine). Smith et al. (2016) birch/deciduous |



#### 6.4.1.1.2 Dead organic matter (key category)

The sink/source category dead organic matter is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

For forest land remaining forest lands on mineral soils, a model approach is used. The model used to estimate C stock changes in mineral soils (see below) provides a change estimate for total soil organic carbon (SOC), which includes the dead wood, litter, and soil pools. The estimate of total SOC entails all stages of decomposition and all C input elements regardless of size and origin (input is aboveground or belowground). The total SOC change estimate was allocated to the dead wood, litter, and soil pools, respectively. This was done by allocating specific chemical model pools to the reporting pools and using the information about the dimension of the C input elements and their origin as aboveground or belowground C input (Figure 6-13). Only the changes in the H pool (humus; Figure 6-13) originating from the belowground C input elements of all sizes were allocated to the changes in the UNFCCC mineral soil sink/source category (1.9%). The remaining change in the total soil organic C stock was attributed to dead wood (16.5%) and litter (81.6%). The allocation percentages were computed once and averaged over the years, i.e., the same allocation percentages were used for all years since 1990. See below for a description of the Yasso07 model, which was used to simulate C stock changes in mineral soils.

| Origin             | Aboveground |   |   |   |   | Belowground |   |   |   |      |
|--------------------|-------------|---|---|---|---|-------------|---|---|---|------|
| Chemical component | A           | W | E | N | H | A           | W | E | N | H    |
| Non woody          | LITTER      |   |   |   |   |             |   |   |   |      |
| Fine woody         |             |   |   |   |   |             |   |   |   |      |
| Coarse woody       |             |   |   |   |   |             |   |   |   |      |
|                    | DEAD WOOD   |   |   |   |   |             |   |   |   |      |
|                    |             |   |   |   |   |             |   |   |   | TIOS |

*Figure 6-13 Conceptual definitions of soil pools based on the chemical composition of Yasso07 output for total soil C stock change. AWENH is defined as Acid soluble, Water soluble, Ethanol soluble, Non-soluble, and Humus.*

For forests on organic soil, it is assumed that the dead organic matter pools are in equilibrium and have zero net carbon stock change on forest land remaining forest land following the Tier 1 methodology (IPCC 2006).

#### 6.4.1.1.3 Mineral soils (key category)

The sink/source category mineral soil is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.0036).

##### Choice of method

A Tier 3 method was applied. The emissions and removals of total soil organic C (dead wood, litter, and soil pools) from forest land on mineral soil are estimated using the decomposition model Yasso07 (Tuomi et al. 2008; Tuomi et al. 2009; Tuomi et al. 2011a; Tuomi et al. 2011b). The Norwegian application is described in Dalsgaard et al. (2016a). Yasso07 represents processes for mineral soils down to a depth of 1 m and operates using five chemical soil C pools (Figure 6-14). Decomposition (CO<sub>2</sub> release) and fluxes among the chemical C pools are regulated by climatic input data and parameters governing C inputs' decomposition, transformation, and fractionation. The model is applied to the time series for each NFI plot. The model is run on an annual time step, but only estimates for the NFI registration years are used. The term "entry" below refers to any combination of an NFI plot and registration year.

For each NFI plot in the category forest land remaining forest land, C changes per hectare since the last measurement of trees on the plot were calculated using Yasso07, as described below. The calculated change was then up-scaled to country-wide estimates using the same method as for tree living biomass, which is described in section 6.3.5.

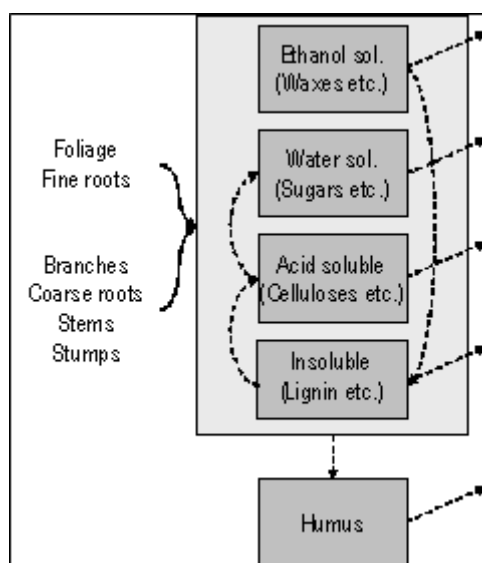


Figure 6-14 Flow diagram for chemical soil C pools in Yasso07. Fluxes significantly different from 0 are indicated by the arrows (Liski et al. 2009).

The model is run for individual plots (or split plots if the plot is divided). For each entry (approximately 11 300 unique NFI plots), annual living tree C input to the model is estimated from tree registrations. On plots where the time series was not complete, backcasting was applied (see section 6.2.2.1). Tree biomass models were used to estimate biomass components (Table 6.15), and annual turnover rates for roots, foliage and branches were applied to estimate the annual C input (Table 6.16 and Table 6.17).

Tree C input generated annually from natural mortality and residues from diffuse harvest (i.e., harvest not including commercial thinning or final harvest) was estimated on all entries as a percentage of the standing biomass. Data from the 8<sup>th</sup> NFI (2000 - 2004) and the 9<sup>th</sup> NFI (2005 - 2009) were used to establish look-up tables for this purpose. Registrations of mortality and harvest on NFI plots started in 1994. The look-up tables are grouped by tree species (broadleaved or conifer), site-index (up to six classes), and age (up to nine classes). Harvest residues from commercial thinning and final harvest were estimated from plot-specific registrations (since 1994) of harvested volume. This C input was relevant on a total of 2013 entries.

The look-up tables mentioned above also contain factors (percentages) describing the biomass development between two inventories. These were used to establish a time series of tree living biomass and harvest residues (commercial thinning and final harvest) back to

1960 (model-input-backcast). Field registrations of the 6<sup>th</sup> inventory (1986 – 1993) on prior land use and forest management activities were used to establish eight rules covering all relevant NFI plots. For young stands where harvest must have occurred during the model-input-backcast period, harvested biomass and biomass of the old stand back in time was estimated using old NFI inventories, where standing volume was generally lower than found in current inventories.

For the GHG inventory, model-input-backcast was done assuming that all plots have always been forested. This assures no double counting in mineral soil, and DOM pools in the transition between methods from “lands to forest” to “forest remaining forest”.

Estimating C input from the model-input-backcast time series (including mortality and diffuse harvest) followed the same procedures as the NFI time series. However, it used average distribution (from NFI) to biomass components as individual tree information is not available in the model-input-backcasted part of the time series. The 1960 - 1990 time-series (model-input-backcast) is used to reduce the effect of the equilibrium assumption on the reported values of soil C change in the inventory period (see below).

**Table 6.15 Biomass models used in Yasso07 simulations.**

**When models from Marklund (1988) are used, the notation “G” is used for Norway spruce and “T” for Scots pine.**

| Component                | Reference and specific model                                                                                                                          |
|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Dead branches</b>     | Marklund (1988), G20, T22, Smith et al. (2014) birch/deciduous                                                                                        |
| <b>Living branches</b>   | Marklund (1988), G12 and G16, T14 and T18, Smith et al. (2014) birch/deciduous                                                                        |
| <b>Foliage</b>           | Marklund (1988), G16, T18, Smith et al. (2014) birch/deciduous                                                                                        |
| <b>Bark</b>              | Marklund (1988), G8, T10, Smith et al. (2014) birch/deciduous                                                                                         |
| <b>Stem</b>              | Marklund (1988), G5, T6, Smith et al. (2014) birch/deciduous                                                                                          |
| <b>Stump</b>             | Marklund (1988), G26, T28 (for Scots pine), Smith et al. (2016) birch/deciduous <sup>a</sup>                                                          |
| <b>Roots (&gt; 5 cm)</b> | Marklund (1988), G28, T31, Smith et al. (2016) birch/deciduous <sup>a</sup>                                                                           |
| <b>Roots (2 mm–5 cm)</b> | Petersson and Ståhl (2006), Bi (for Norway spruce, Scots pine)<br>Marklund 1988, G28, G26, T31, T28, Smith et al. (2016) birch/deciduous <sup>a</sup> |
| <b>Roots (&lt; 2 mm)</b> | 0.3 × foliage biomass; (Kjønaas et al. Manuscript)                                                                                                    |

<sup>a</sup> No distinct diameter limit is inferred between the two classes of deciduous coarse roots.

**Table 6.16 Annual turnover rates applied for tree C input estimation.**

**Compiled in Peltoniemi et al. (2004) and de Wit et al. (2006).**

| Component      | Norway spruce | Scots pine | Broadleaved | Reference                |
|----------------|---------------|------------|-------------|--------------------------|
| <b>Foliage</b> | 0.143         | 0.33       | 1           | Tierney and Fahey (2002) |

|                                                |        |       |       |                                                                                    |
|------------------------------------------------|--------|-------|-------|------------------------------------------------------------------------------------|
| <b>Live and dead branches, roots &gt; 2 mm</b> | 0.0125 | 0.027 | 0.025 | Muukkonen and Lethonen (2004)<br>DeAngelis et al. (1981)<br>Lethonen et al. (2004) |
| <b>Roots &lt; 2 mm</b>                         | 0.6    | 0.6   | 0.6   | Matamala et al. (2003)                                                             |

The C input generated from the ground vegetation is estimated using models based on plot tree species and age (Muukkonen & Mäkipää 2006; Muukkonen et al. 2006). A distinction is made among Norway spruce, Scots pine, and deciduous (birch spp.), with an age span of 0-200 years (Norway spruce and Scots pine) or 0-100 years (deciduous). The output of aboveground biomass is generated for four layers of ground vegetation: i) moss, ii) lichens, iii) herbs and grasses, and iv) shrubs. For shrubs, herbs, and grasses, it is assumed that belowground biomass is twice the aboveground biomass (e.g. Poeplau (2016)). A compilation of studies documenting the above-to belowground-ratio for biomass and the annual turnover rates for ground vegetation litter (Table 6.17) can be found in Peltoniemi et al. (2004).

| <b>Table 6.17 Annual turnover rates for litter from ground vegetation.</b> |      |         |                   |        |
|----------------------------------------------------------------------------|------|---------|-------------------|--------|
| <b>Component</b>                                                           | Moss | Lichens | Herbs and grasses | Shrubs |
| <b>Aboveground</b>                                                         | 0.33 | 0.1     | 1                 | 0.25   |
| <b>Belowground</b>                                                         | -    | -       | 0.33              | 0.33   |

The chemical composition of tree C input was based on data used to develop the Yasso07 model. For ground vegetation litter, the values of C input in Peltoniemi et al. (2004) were used (Table 6.18).

| <b>Table 6.18 The fraction of C input made up of acid soluble (A), water soluble (W), ethanol soluble (E), and insoluble (N).</b> |            |             |            |            |
|-----------------------------------------------------------------------------------------------------------------------------------|------------|-------------|------------|------------|
| <b>Component<sup>a</sup></b>                                                                                                      | A          | W           | E          | N          |
| <b><u>Stem</u></b>                                                                                                                |            |             |            |            |
| Norway spruce                                                                                                                     | 0.63, 0.7  | 0.03, 0.005 | 0, 0.005   | 0.33, 0.28 |
| Scots pine                                                                                                                        | 0.66, 0.68 | 0.03, 0.015 | 0, 0.015   | 0.29, 0.28 |
| Deciduous                                                                                                                         | 0.65, 0.78 | 0.03, 0     | 0          | 0.32, 0.22 |
| <b><u>Roots (&lt;2mm)</u></b>                                                                                                     |            |             |            |            |
| Norway spruce                                                                                                                     | 0.5508     | 0.1331      | 0.0665     | 0.2496     |
| Scots pine                                                                                                                        | 0.5791     | 0.1286      | 0.0643     | 0.228      |
| Deciduous                                                                                                                         | as foliage | as foliage  | as foliage | as foliage |
| <b><u>Foliage</u></b>                                                                                                             |            |             |            |            |
| Norway spruce                                                                                                                     | 0.4826     | 0.1317      | 0.0658     | 0.3199     |
| Scots pine                                                                                                                        | 0.5180     | 0.1773      | 0.0887     | 0.2160     |

|                                             |               |               |               |                |
|---------------------------------------------|---------------|---------------|---------------|----------------|
| <b>Deciduous</b>                            | 0.4079, 0.46  | 0.198, 0.1929 | 0.099, 0.0964 | 0.2951, 0.2507 |
| <b><u>Living and dead branches</u></b>      | as stem       | as stem       | as stem       | as stem        |
| <b>Norway spruce</b>                        | 0.3997-0.5307 | 0.0105-0.0295 | 0.0382-0.1309 | 0.411-0.4608   |
| <b>Scots pine<sup>b</sup></b>               | as stem       | as stem       | as stem       | as stem        |
| <b>Deciduous</b>                            |               |               |               |                |
| <b>Roots &gt; 2 mm</b>                      | as branches   | as branches   | as branches   | as branches    |
| <b>Stumps</b>                               | as stem       | as stem       | as stem       | as stem        |
| <b>Bark</b>                                 | as foliage    | as foliage    | as foliage    | as foliage     |
| <b><u>Ground vegetation<sup>c</sup></u></b> |               |               |               |                |
| <b>Moss</b>                                 | 0.74          | 0.0867        | 0.0433        | 0.13           |
| <b>Lichens</b>                              | 0.836         | 0.0747        | 0.0373        | 0.052          |
| <b>Herbs and grasses</b>                    | 0.27          | 0.4667        | 0.2333        | 0.03           |
| <b>Shrubs</b>                               | 0.56          | 0.2067        | 0.1033        | 0.13           |

<sup>a</sup> The majority of values are from the Yasso07 user manual (Liski et al. 2009). <sup>b</sup> 25 observations were available. The range is given. <sup>c</sup> From Peltoniemi et al. (2004): W is 2/3 of "extractable"; E is 1/3 of "extractable".

The C input was either non-woody (foliage, fine roots, all ground vegetation input), fine-woody (living and dead branches, coarse roots, and bark), or coarse-woody (stems and stumps). The dimensions entering Yasso07 for each of the three size-groups are 0, 2, and 10 cm, respectively. The mean C input for all entries is found in Table 6.19.

| <b>Table 6.19 Mean values for C input and predicted soil C (distributed by litter pools).</b><br>Each entry is weighted by its appropriate NFI area weight (which differ among the NFI strata). |                  |                   |                     |              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------------------|---------------------|--------------|
| <b>Category</b>                                                                                                                                                                                 | <b>Non-woody</b> | <b>Fine-woody</b> | <b>Coarse-woody</b> | <b>Total</b> |
| <b><i>C input (tC ha<sup>-1</sup> yr<sup>-1</sup>)</i></b>                                                                                                                                      |                  |                   |                     |              |
| Ground vegetation                                                                                                                                                                               | 0.40             |                   |                     | 0.40         |
| Tree living biomass                                                                                                                                                                             | 0.88             | 0.22              |                     | 1.09         |
| Natural mortality                                                                                                                                                                               | 0.01             | 0.06              | 0.06                | 0.13         |
| Commercial harvest                                                                                                                                                                              | 0.03             | 0.13              | 0.04                | 0.20         |
| Other harvest                                                                                                                                                                                   | 0.01             | 0.03              | 0.01                | 0.05         |
| <b>Total</b>                                                                                                                                                                                    | <b>1.32</b>      | <b>0.44</b>       | <b>0.11</b>         | <b>1.87</b>  |
| <b><i>Equilibrium stock (tC ha<sup>-1</sup>)</i></b>                                                                                                                                            |                  |                   |                     |              |
| Ground vegetation                                                                                                                                                                               | 9.79             |                   |                     | 9.79         |
| Tree living biomass                                                                                                                                                                             | 25.70            | 6.57              |                     | 32.27        |
| Natural mortality                                                                                                                                                                               | 0.30             | 1.77              | 4.15                | 6.22         |
| Commercial harvest                                                                                                                                                                              | 0.81             | 3.53              | 2.54                | 6.89         |
| Other harvest                                                                                                                                                                                   | 0.20             | 0.94              | 0.56                | 1.70         |
| <b>Total</b>                                                                                                                                                                                    | <b>36.79</b>     | <b>12.82</b>      | <b>7.26</b>         | <b>56.86</b> |
| <b><i>Predicted stock* (tC ha<sup>-1</sup>)</i></b>                                                                                                                                             |                  |                   |                     |              |
| Ground vegetation                                                                                                                                                                               | 9.67             |                   |                     | 9.67         |
| Tree living biomass                                                                                                                                                                             | 26.65            | 6.69              |                     | 33.34        |
| Natural mortality                                                                                                                                                                               | 0.31             | 1.80              | 4.22                | 6.33         |
| Commercial harvest                                                                                                                                                                              | 0.91             | 3.88              | 2.73                | 7.52         |
| Other harvest                                                                                                                                                                                   | 0.21             | 0.99              | 0.57                | 1.77         |
| <b>Total</b>                                                                                                                                                                                    | <b>37.75</b>     | <b>13.36</b>      | <b>7.52</b>         | <b>58.64</b> |

\*Across all entries in the time-series, excluding backcast entries.

For each NFI plot, start values for the five chemical C pools (Figure 6-14) were obtained by a pre-simulation or spin-up. This was done in two steps: 1) running the model in 5000 annual time steps to equilibrium in all chemical pools<sup>35</sup> and 2) running the model for a C input time series 1951 - 1990 specifically constructed for this purpose (see above). The C input for the equilibrium spin-up was the mean C input estimated for the historical time series (1986 - 2016), grouped by tree species and site-index. For the model-input-backcast and inventory periods, the total SOC was estimated for each entry, i.e., each time a registration was available. Plot-specific total SOC was obtained as follows: estimated annual C input of individual plots for each entry in the time-series was used as input. The C stock from the

<sup>35</sup> Increasing the spin-up time to 15000 annual time steps resulted in C stock changes of 0.03% lower and C stocks of 0.09% higher than with the chosen standard of 5000 steps (mean values across all plots).

previous entry was used as the start value. A loop was applied to drive the model in as many years as was found between the entries (mostly five years, but this deviates in some cases in the early inventory years). For the first entry, a loop of five years was applied following the spin-up stock.

The C inputs and the simulated soil organic C stocks are kept in units of kg C m<sup>-2</sup>. The Graphical User Interface parameter set for Yasso07 was applied (Tuomi et al. 2011b). To return the reported time series, interpolation was done the same way as for the tree living biomass estimates.

Climate data was also used as input for the Yasso07 model. Many of the same variables used to derive plot-specific IPCC climate regions were applied (see section 6.3.2 for technical specifications and references). The Yasso07 model uses MAT, MAP, and annual temperature amplitude, which is the absolute difference in MMT between the month with the highest MMT and the month with the lowest MMT, divided by 2. Climate data for the equilibrium spin-up was the plot-specific climatic normal for the last 30 years prior to observations. For most plots, the last 30-year period is within 1957-1992. For the remainder of the time series simulations, plot-specific climate data was applied, using backwards-looking dynamic 5-year moving average annual values from 1957 - 2021.

The estimated total SOC changes between entries in the time-series have been distributed between the dead wood, litter, and soil sink/source categories described above under the section on dead organic matter.

#### Activity data

Various input data were used to estimate C stock changes in DOM and mineral soil. This includes climate data (see above and section 6.3.2), area representation for plots (as described for the NFI), basic NFI registrations (as described for the tree living biomass), as well as site-index and stand age, complementary models and parameters including biomass models, turnover rates, chemical C input composition, and C input dimensions. The usage and values of input data are described under the section *Choice of method* above.

Plots recorded as forest land remaining forest land with no tree biomass for the entire time series were excluded from the DOM and mineral soil estimates. These plots may have had tree biomass but are not visited by surveyors for good reasons (military zones or other inaccessible areas). Hence no tree biomass is registered. Additionally, plots lacking site-index or tree stand age were excluded from the DOM and mineral soil estimates due to the



specific methods being used requiring such input. With no input for the model, these plots must be assumed to have a default net-zero change for DOM and mineral soil.

The registration of ditches in all NFI plots in the period 2016-2020 revealed an area of 445 kha of drained mineral soil on forest land remaining forest land. No method is currently available for drained mineral forest soils. All mineral soil C stock changes on forest remaining forest land were estimated as described above regardless of drainage status.

#### Assumptions/justification

The NFI definition of mineral soil is based on the depth of the organic layer (< 0.4 m). We assume that the decomposition processes in these areas are represented by the model structure and the parameters of the Yasso07 model obtained from data on mineral soils throughout the world. A more detailed delineation between mineral and organic soils (based on soil taxonomical classification) is currently not possible.

The allocation to the dead wood, litter, and soil pools assumes no vertical transport of the chemical fractions from the aboveground pools to the mineral soil (below ground) (see Figure 6-13). Thus, changes in soil organic C originating from aboveground litter in all stages of decomposition are assumed to be found in the organic layer above the mineral soil. While this is not strictly to be expected in reality, all soil organic C is accounted for, and assumptions related to the distribution of the dead wood, litter, and soil pools do not affect the total emissions/removals. The assumptions result in a small part of the total change allocated to the soil pool. According to field studies, changes in the mineral soil are very slow and are often not significantly different from zero (Emmett et al. 2007; Peltoniemi et al. 2004).

#### 6.4.1.1.4 Drained organic soils (key category)

The source category drained organic soil is identified as a key category for Level assessment 1990 and Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).

CO<sub>2</sub> emissions from drained organic soils on forest land is a key category. Due to the lack of national emissions factors, a Tier 1 method was chosen.

#### Activity data

Ditch records on the national scale are available from the 1950s (SSB, subsidy statistics). According to these data, there was an increase in the area drained annually in the 1950s, with a peak of approximately 13 kha yr<sup>-1</sup> in the early 1960s. Since then, establishing drainage ditches to facilitate forest production became much less practised, and establishing drainage ditches on mires with the aim of forest production was prohibited by

law in 2007. Until 2007, a total accumulated area of 241 kha was reported as drained for forestry, according to Statistics Norway. In the years 2016-2020, the presence of ditches was recorded on all plots in the Norwegian NFI, and these records were used as activity data for emissions from drained organic forest soil (as well as for CO<sub>2</sub> in Wetlands (section 6.7) and non-CO<sub>2</sub> emissions in Wetlands and forest land (section 6.12)). All drained organic soil is found in the temperate cool climate zone, and accordingly, only the climate zone determines the default emission factor for CO<sub>2</sub> emissions (IPCC 2014b).

The NFI routinely records the management activities conducted on the plots 5 years prior to each field visit (see also section 6.3.1). Time of ditching was determined as follows; i) if “ditching” was recorded as a management activity in the NFI time series, then the presence of a ditch was assumed to go back as far as to the year of that record (thus not prior to the management activity record), ii) if a plot is split during the time series (to road, settlements or cropland, and the ditch is described as type “road-ditch” or “edge-ditch” directly bordering to croplands or settlements) then it is assumed that ditches were established in connection with the land-use change, i.e. the ditch is assumed to have been present since the year where the split occurred, iii) for cases where a ditch was recorded in 2016 or later but no NFI records prior to 2016 indicated management activities or land-use change, it was assumed that the ditch was also present in 1990, thus throughout the time series. This was the case for most plots where ditches were recorded in 2016 or later. In the field, the length and width of ditches were measured and used to establish a national factor, “frac ditch”, see section 6.12.2.

#### Emission factors

We used the default emission factor for temperate cool climate from the IPCC 2013 Wetlands supplement, 2.6 t C-CO<sub>2</sub> yr<sup>-1</sup> ha<sup>-1</sup>, as it represents the most up-to-date information.

#### 6.4.1.1.5 Undrained organic soils

Organic soils on forest land not subject to drainage were assumed to be in equilibrium. No methods are available for estimating the C emissions or removals in these areas. Based on NFI registrations since 1990, final harvest or thinning has been registered on about 8% of the forest area on organic soil not subject to drainage and on 22% of the forest area on mineral soil (NFI definition of forest, i.e., including areas in conversion in UNFCCC terminology). Thus, forestry activities in areas with undrained organic forest soils are relatively low. A study was conducted to survey existing empirical evidence on C emissions/removals from undrained organic forest soils. A total number of 30+ publications reporting on open and tree-covered bogs and fens in countries including Finland, Sweden, Canada, and Russia were included in the survey. The overall conclusion was that these areas have been long-term C sinks (for millennia, based on peat column studies), and contemporary rates (short-term studies 1-10 years) indicate that they, on average and in most years, act as sinks, but that they in some (dry) years may act as a source. Where comparisons have been made between open and tree-covered areas, there were no indications that open areas had higher accumulation rates than tree-covered areas. Comprehensive studies include Tolonen and Turunen (1996), Turunen et al. (2002), Roulet et al. (2007), and Nilsson et al. (2008).

### 6.4.1.2 *Uncertainties and time-series consistency*

#### 6.4.1.2.1 Living biomass

The estimation of uncertainties for C stock changes in tree living biomass on forest land is described in section 6.3.7, and estimated uncertainties are presented in Table 6.3. The calculations of C stock changes in tree living biomass are conducted according to the stock change method and are based on data obtained from the NFI. More details are described in section 6.3.5.

#### 6.4.1.2.2 Dead organic matter and mineral soils

The uncertainties for dead organic matter and mineral soil used in the key category analyses are based on Monte Carlo simulations (performed in 2014) of the national level of total soil organic C change (i.e., soil + litter + dead wood). The technique consists of running a thousand simulation loops, assigning random values within a specified range (see Table 6.20) to uncertain parameters to predict possible outcomes.

| <b>Table 6.20 Characteristics of the parameters used in the Monte Carlo simulations.</b> |                              |                                                                                       |                                |                                                              |
|------------------------------------------------------------------------------------------|------------------------------|---------------------------------------------------------------------------------------|--------------------------------|--------------------------------------------------------------|
| <b>Parameter</b>                                                                         | Distribution                 | Mean                                                                                  | Standard deviation (% of mean) | References                                                   |
| <b>Coarse woody litter dimension (cm)</b>                                                | Normal                       | 10                                                                                    | 20%                            | Expert judgment                                              |
| <b>Branch and coarse root turnover (yr<sup>-1</sup>)</b>                                 | Normal                       | 0.0125; 0.027; 0.025 <sup>a</sup>                                                     | 20%; 25% <sup>b</sup>          | Peltoniemi et al. (2006); expert judgment                    |
| <b>Fine root turnover (yr<sup>-1</sup>)</b>                                              | Lognormal                    | 0.6 <sup>c</sup>                                                                      |                                | (Brunner et al. 2013) (Hansson et al. 2013); expert judgment |
| <b>Foliage turnover (yr<sup>-1</sup>)</b>                                                | normal; uniform <sup>b</sup> | 0.143; 0.33; 0.9-1.0 <sup>a</sup>                                                     | 15%                            | Peltoniemi et al. (2006); expert judgment                    |
| <b>Ground vegetation turnover (yr<sup>-1</sup>)</b>                                      | Normal                       | 0.33; 0.1; 1.0; 0.25 (aboveground) <sup>d</sup> 0.33; 0.33 (belowground) <sup>e</sup> | 40%                            | Peltoniemi et al. (2006)                                     |
| <b>Biomass ratio for ground vegetation, below-to-above</b>                               | Normal                       | 2                                                                                     | 20%                            | Peltoniemi et al. (2006)                                     |

<sup>a</sup> Spruce, pine and deciduous, respectively. <sup>b</sup> Conifers and deciduous, respectively. <sup>c</sup> In lognormal: mean -0.51 and standard deviation 0.3. <sup>d</sup> Moss, lichens, herbs/grasses and shrubs, respectively. <sup>e</sup> Herbs, grasses, and shrubs.

Uncertainty around the Yasso07 model parameters has been described in a number of parameter sets (Tuomi et al. 2011b), where covariance among model parameters is taken into consideration. A number of parameters related to model input were selected because they were assumed to have particularly large uncertainties for the C input parameters. The C input parameters were assumed to be independent of each other, but in cases where differences among species or specific components could not be documented, parameter values were drawn from the same distribution. Most parameters were assumed to be normally distributed, and negative values were avoided by truncated distributions (negative values replaced by 0). The simulations were run with the Yasso07 model, with spin-up loops coded in Fortran, and the litter estimation was run with the R software (R Core Team 2015). The result was an uncertainty estimate of the Yasso07 simulated C stock changes reported in 2014 of 15.5%, which applied to both the DOM and mineral soil pools. Uncertainties were estimated for an older methodology where climate input to Yasso07 was not dynamic. This level of uncertainty is also assumed for the current inventory despite some changes to the methodology.

Uncertainties in the biomass models (Table 6.20) and the diffuse harvest and mortality frequencies underlying the C input estimates to Yasso07 are currently ignored, mainly for technical reasons. However, we presume that most of the uncertainty associated with the current methodology is captured.

#### 6.4.1.2.3 Drained organic soils

Default uncertainties of the emissions factors from the IPCC 2013 Wetlands Supplements were applied, and uncertainties of the areas were estimated by sample error. See Table 6.4.

#### 6.4.1.3 Verification

##### Litter, dead wood, and mineral soil using Yasso07

Yasso07 (Tuomi et al. 2009; Tuomi et al. 2011a; Tuomi et al. 2011b) is developed from Yasso (Liski et al. 2005) with parameters estimated with novel statistical methodology (Markov chain Monte Carlo) from global data on forest litter decomposition including both fine and coarse litter and litter of different chemical compositions. The model is designed specifically for linking to forest data from national forest inventories.

The model is used for UNFCCC reporting for forests in several countries, e.g., Finland, Switzerland, and Austria (see below and a list on the Yasso-homepage: <https://en.ilmatieteenlaitos.fi/yasso-publications>). Norway applies Yasso07 as we believe it represents the most important drivers of short-term changes in C-pools of mineral soil, litter, and deadwood since it is a model that matches the level of detail for the information (input data) that we currently have available from our NFI.

The most detailed description of the Norwegian application is found in (Dalsgaard et al. 2016a). Norway does not have independent soil C data sets that can verify whether the modelled predictions of changes are valid for the country as a whole. Two programs have been started to obtain such independent data for model verification/evaluation (items I and II described later). However, Norway has applied some alternative means of verification/evaluation of the model output. See below as well as the conclusions from a validation project in (Dalsgaard et al. 2017).

Using Yasso07 for estimating short term changes in soil C and DOM ensures that pools are not assumed in equilibrium (as in Tier 1) and as forest biomass and climate are both known to not be in equilibrium, an equilibrium assumption for soil C and DOM would not be a sound assumption.

The estimated C stocks from Yasso07 were low compared to field measurements (de Wit & Kvindesland 1999). Studies with an earlier version of Yasso (de Wit et al. 2006), showed that the model estimated about 40% of the measured forest soil C stock in southeast Norway. This was suggested to be due, in part, to an overestimation of decomposition rates for recalcitrant organic matter. Later comparisons of model and measured soil C stocks confirmed that Yasso07 underestimates measured stocks and that it may be related to soil type and moisture condition (Dalsgaard et al. 2016a)

Efforts to verify the model for changes have been based on both literature (comparing to other countries and regions e.g., (Dalsgaard et al. 2017) and measurements on a few individual sites (Kjønaas et al. 2017; Lange et al. 2017).

Based on the experience we have gained we believe that Yasso07 is a suitable model for predicting short term changes in soil, litter, and deadwood on mineral soil types on a national (possibly regional) scale for the following reasons:

- Estimates for Yasso07 for Norwegian forest (18 g C/m<sup>2</sup>yr; aggregated to national scale) are within the range found for neighboring countries (Dalsgaard et al. 2017):
  - Finland (11-12 g C/m<sup>2</sup>yr) (measurements, (Rantakari et al. 2012); and the Finnish GHG inventory 2014 for the DOM and SOC pools)
  - Sweden (18-20 g C/m<sup>2</sup>yr) (SOC + DOM in the GHG inventory 2014)
  - Sweden (12-13 g C/m<sup>2</sup>yr and 6-7 g C/m<sup>2</sup>yr) (model estimates 1926-2000 using two alternative models; (Ortiz et al. 2013; Ågren et al. 2008)
  - Sweden (25 g C/m<sup>2</sup>yr) (humus layer; (Berg et al. 2009)
  - Current reporting of soil, litter, and deadwood (combined; as they are estimated combined in Yasso07) are in the same order of magnitude as Finland and Sweden (see Figure 6-15) and, after changing climate input to Yasso07 from long term averages to 5-year averages, NIR2021, the estimated accumulation estimates have decreased and stabilized (i.e., any changes in historical climate are now accounted for in the decomposition rates). Yasso07 estimated changes for a selected region in south-east Norway close to Sweden shows that estimates are quite similar to those in Sweden i.e., Swedish measurement-based estimates (see caption Figure 6-15).

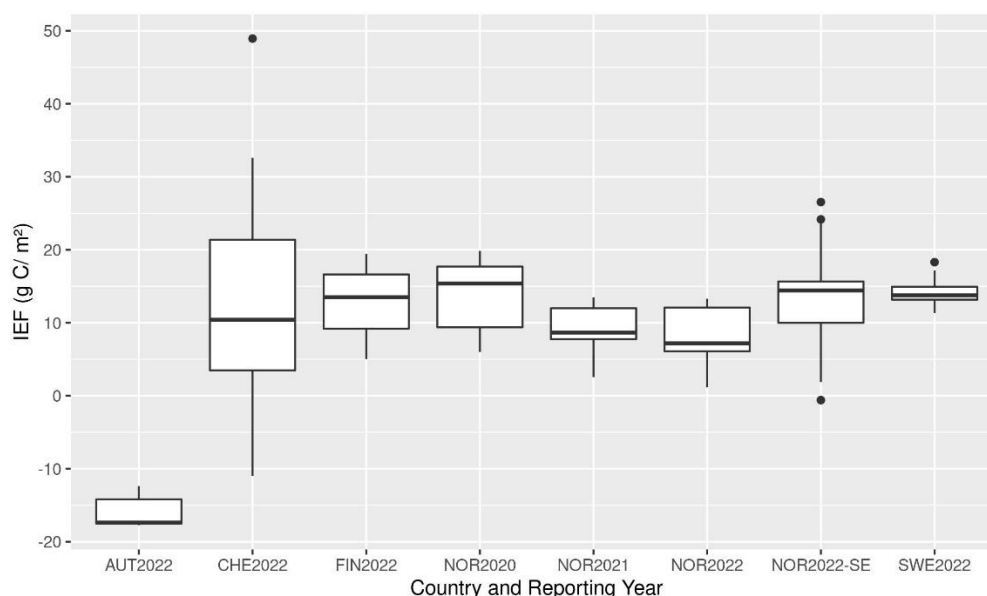


Figure 6-15 Boxplot of the sum of implied emission factors (IEF) for dead wood, litter and mineral soil for Forest land remaining Forest from CRF tables for the countries Austria (AUT), Switzerland (CHE), Finland (FIN), Sweden (SWE) and Norway (NOR). With the exception of Sweden, all countries presented use Yasso for dead wood, litter and mineral soil carbon stock change (CSC). Sweden uses soil measurements. Each boxplot consists of IEF for all the years for a given reporting year (the number after the country abbreviation). For Norway reporting years 2020, 2021, and 2022 are presented. In NOR2020 constant / static climate data was used with Yasso07. In NOR2021 dynamic climate data (5-year backwards looking moving average) was used with Yasso07. In NOR2022 dynamic climate data (5-year backwards looking moving average) and updated scripts were used with Yasso07. NOR2022-SE is a selection of plots found in South-Eastern Norway (plots found within the boundaries latitude 59.2511 to 61.2351 and longitude 9.4486 to 13.4752). Norway's climate and forest ecology varies from region to region. South-Eastern Norway is expected to be relatively similar to a large part of Sweden. The boxplots show that estimates from Norway are similar to the neighbouring countries Finland and Sweden, and within the larger span of Switzerland. South-eastern Norway is especially closer to estimates from Sweden. Austria seems to be the outlier. This may, however, be due to CRF data extraction issue, as some data were indicated as IE. Overall, the comparison of boxplots suggest that Yasso07 model is capable of producing reasonable estimates for Norwegian climate and forest ecology and specifically for the south-eastern region.

- Measurements and Yasso07 simulations of changes in soil C at two sites in the southeastern parts of Norway (stands established/planted in 1973 and 1976 and both sites are situated within the latitude and longitude ranges used for NOR2022-SE in Figure 6-15; (see details in Lange et al. (2017) and Kjønnaas et al. (2017)) indicated that measured and modelled estimates (averaged to annual change over the time series

from 1978-2012) were close to the 1:1 – line as compared to other studies e.g. Mao et al. (2019) for France over 15 years; Ziche et al. (2019) for Germany over 29 years (Figure 6-16). In the studies for France and Germany (above), Yasso07/Yasso15 were used for a large population of different individual forest stands and both studies included sites with deviations in annual changes for soil C between measurements and simulations of approximately 300 g C/m<sup>2</sup>yr):

- At one site, “Nordmoen” (well drained podzol), Yasso07 estimated SOC stocks similar to measured stocks. Simulated changes (g C/m<sup>2</sup>yr) averaged for the time period 1978-2012 ranged between an annual loss of 21 g and an annual accumulation of 69 g; measured changes ranged between an annual loss of 18 g and an annual accumulation of 4 g.
- At the other site, “Skiptvet” (drained before the first forest rotation which was harvested in the mid-sixties; previous agricultural use), Yasso07 estimated a lower SOC stock compared to measurements. Yasso07 simulated an average annual loss (g C/m<sup>2</sup>yr) between 22 and 27 g and the measured changes were between an annual loss of 103 g and an annual accumulation of 17 g. In studies comparing Yasso07/Yasso15 with measured changes, deviations of approx. 300 g C/m<sup>2</sup>yr are not uncommon; see above.
- We acknowledge that measurements of C stock changes based on only two sites are insufficient for Yasso07 model validation at the national scale. However, it supports the conclusion of the comparison of Norway with neighboring countries that estimates of C stock changes from Yasso07 are within the expected range.



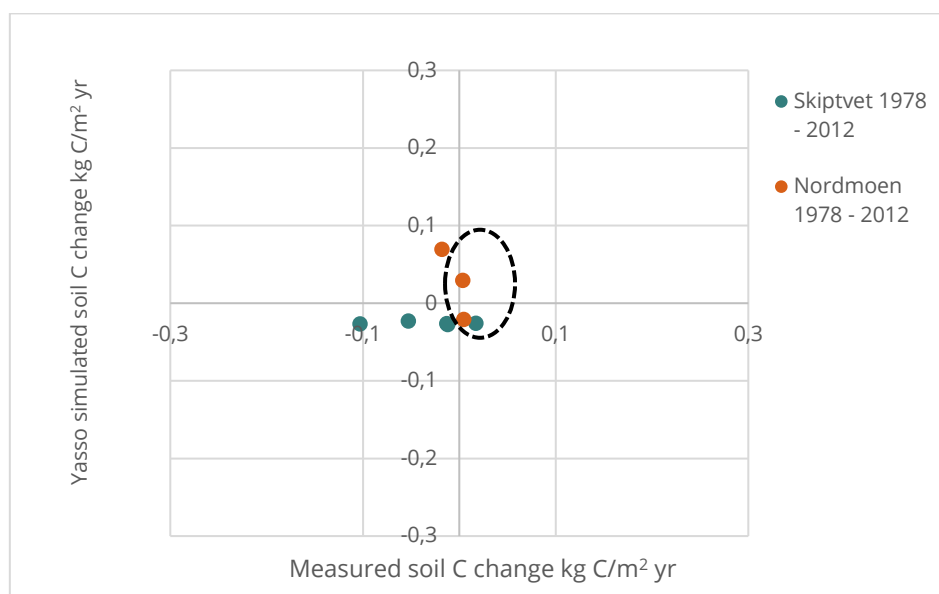


Figure 6-16 Mean annual changes 1978-2012 for measured and simulated soil C. For the site “Skiptvet” the different point (treatments) are different mixtures of spruce and birch. For the site “Nordmoen” the treatments are monocultures of birch (highest simulated change), pine (intermedium simulated change) and spruce (simulated loss). For the “Skiptvet” site, the measured losses may partly be due to the site history indicating that the site was drained (see main text) and this was not reflected in the way the Yasso07 was used (model initialization). Figure is unpublished, data are derived from Lange et al. (2017). X- and y-scales are the same as in Mao et al. (2019) and Ziche et al. (2019). For both sites, small rates of soil C accumulation (positive change, indicated by bold oval in the figure) was measured for spruce (or treatments systematically favouring spruce) and pine whereas for stands with only birch or a significant proportion of birch (birch/spruce mixtures), a loss in soil C was measured. Such potential effects of birch (or birch mixture) on these sites and soils have not been investigated in detail and do not seem to be reflected in the Yasso07 simulations.

- Yasso07 estimates were found to be representative for the decomposition of litter and dead wood in a national scale Swiss data set that is expected to include substantial climatic variability – which is also the case for Norway (Didion et al. 2014).
- Yasso07 was found to estimate changes within the error bounds of measured changes in Finland (Rantakari et al. 2012) and in Sweden (Ortiz et al. 2013). The Finnish study applied both long term and annually averaged climate input and while the best representation was indicated for long term averages, the model application with annual climate data was also within the error bounds for measured changes.

Norway acknowledges that the documentation presented here can only serve as an alternative means of verification. Points 1, 2 and 4 are relevant mainly for the south-eastern part of Norway where more than 40 % of Norway's forest is located. In addition, points 1 and 4 are relevant for areas to the north-east, i.e., relatively dry regions. Most coastal forests in Norway have soils, vegetation, and climate (and management) that are not comparable to our neighboring countries (see also Dalsgaard et al. (2016b) and Bright et al. (2020) for discussions of primarily long-term soil development (stocks) and plant litter production) and the challenges for Yasso07 to represent the short-term soil dynamics found in these forests must be resolved with Norwegian data once available. Thus, further work is necessary to verify the Yasso07 on the national scale, and this has high priority in Norway. Two parallel data sources are currently being developed:

- I. In 2022, Norway started to develop a national soil carbon monitoring program within the NFI that will produce independent data which can be used to verify (evaluate) the Yasso07 on a national scale. Data collected during an earlier soil survey in 1988-1992 does not qualify as a baseline for soil carbon due to the field methodology used at that time. Thus, sampling needs to be repeated to get change estimates for SOC, and due to this and the magnitude of sampling all over Norway, it will take 15-20 years until a data set on SOC changes representative for the national scale will be available for a model verification (evaluation). The first data in the program will be collected in 2023. The first data for SOC changes will be available in 2035.
- II. In 2022 soil data from three experimental forest sites with base-line SOC data from approximately 2011-2013 were collected. Funding is required to start a project for model evaluation on these three sites (in addition to the two sites where data is illustrated in Figure 6-16). The five sites (Figure 6-17) make up a subset of a total of 17 sites where such base-line SOC data are available (most SOC data prior to 2011 in Norway do not qualify as base-line data for SOC). Most sites are found in the south-east, where also most of the forest is located.

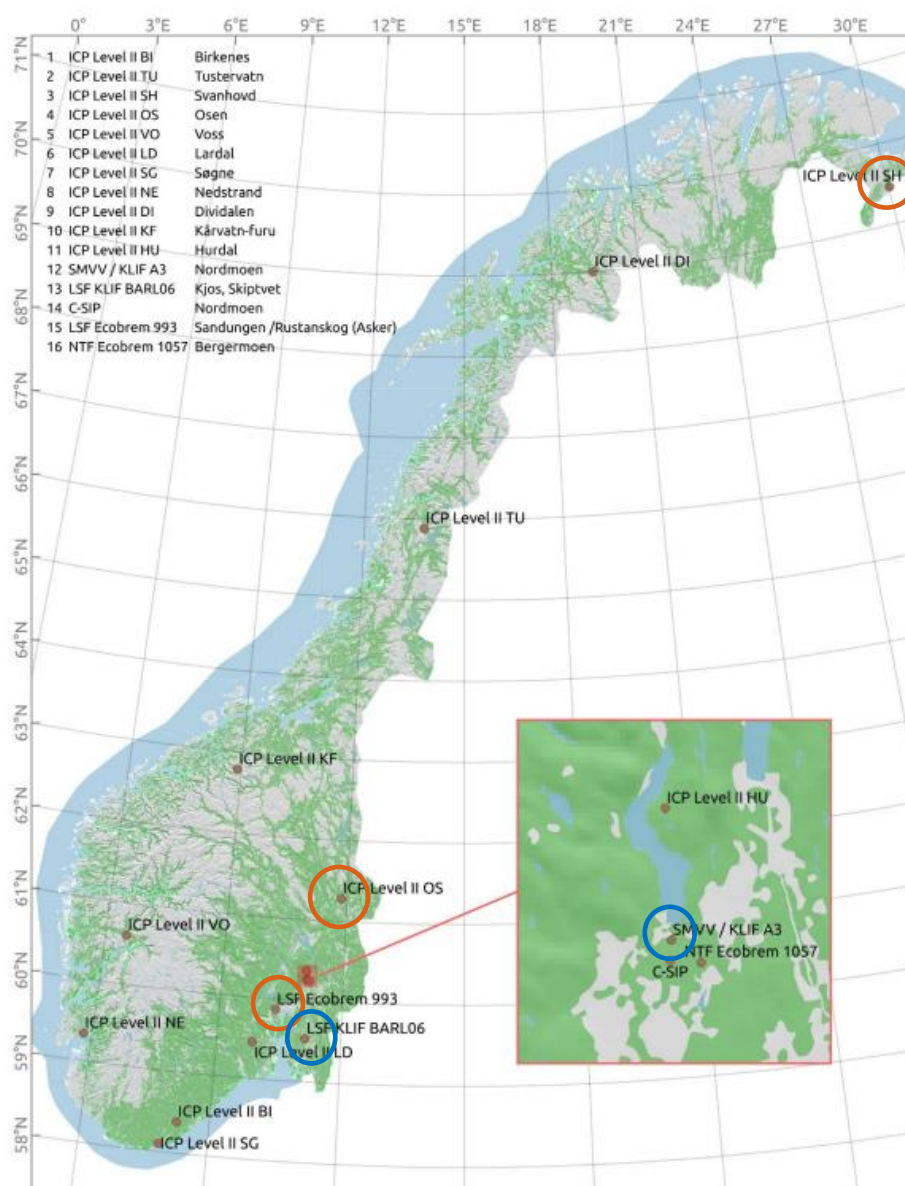


Figure 6-17 Experimental forest sites where base-line SOC from approximately 2010 is available and repeated soil sampling is relevant for site specific comparison of model and measured SOC change. Blue circles show the sites where SOC change was measured and simulated in 2017 (see above), and orange circles show sites where SOC changes were measured in 2022 but where comparison to simulated changes are not yet performed. The map is produced by NIBIO.

#### 6.4.1.4 QA/QC

The QA/QC plan was performed according to the Tier 1 procedure. Similar to the area estimates, the carbon change estimates were carried out by two people independently and compared on an aggregate and a sample plot basis.

The NFI database has QA/QC procedures, as explained in section 6.1.6 and Annex V.

For the estimation of C changes in mineral soils on forest land, the unit from the input from the NFI data base was changed into tC/ha (conversion to kgC/m<sup>2</sup> prior to running the Yasso07). When combined with other sources unit was tC/ha. Specific attention was given to unit conversions, particularly when data were moved from one platform to another. The input data were screened for inconsistencies, i.e., the occurrence of null-data/missing data, length of input objects etc. Plot-specific C input, scaled in an expected manner with total plot standing biomass and plot-specific soil organic C changes, had the expected dynamics (i.e., on average, C change on the plot level was negative or low in young stands vs medium age stands). Average litter input and total SOC output time series were compared with those used in the previous year's NIR.

The method (model combined with NFI data) for estimating C changes in soil and DOM for Forest Remaining Forest was completely re-coded in 2021-2022 in order to make this code fit better with scripts producing other parts of the inventory. The aim was to reproduce the functionality of the old code, potentially changing (improving) functionality in the future. Throughout the work with re-coding, comparisons were made for input data and output results between the old and the new code. Final upscaled output, i.e., reported changes were close for the two codes with deviations most likely caused by: updates in meteorological data and choices in the gap-filling procedure for missing NFI-variables and choices associated with the pre-simulation (equilibrium prior to 1960 and time series prior to 1990).

QC was performed by compiler and expert in collaboration.

#### 6.4.1.5 Recalculations

##### Living biomass

A large recalculation for living biomass has occurred in the last years due to an extrapolation update (see section 6.3.5). The increase in emissions is explained by the increase in harvest after 2009.

Dead organic matter and mineral soils

Litter, dead wood, and mineral soil have been recalculated for the whole time-series due to updates to the climate data used by Yasso07 and the backwards-looking moving-average methodology. In addition, there was a change in the period calculation to ensure that mineral soil, litter, and dead wood at equilibrium are set consistently 30 years from the reporting period.

Drained organic soils

The time series were recalculated due to updates in the NFI database.

See chapter 10.2.4. for details.

**6.4.1.6 Planned improvements**Living biomass, dead organic matter, mineral soils, and drained organic soils.

Verification of the estimates on CSC in mineral soil and DOM are planned. See chapter 10.4 of this document for details.

**6.4.2 Land converted to forest land, 4A2**

Land converted to forest land occurs from all land uses except other lands. The largest area changes come from extensive grassland, followed by settlements. In the case of settlements, many types of settlements have been converted to forest land in Norway. These can roughly be divided into four groups: power lines, roads, extraction (i.e., gravel, sand, and mining), and others. Estimates of C stock changes are provided for living biomass, dead organic matter (DOM), mineral soils, and organic soils for all relevant conversions. Conversion from extensive grassland to forest land is almost exclusively due to natural succession.

**6.4.2.1 Methodological issues****6.4.2.1.1 Living biomass (key category)**

The sink/source category living biomass on land converted from intensive grassland, cropland and unmanaged wetlands to forest land are identified as key categories for Level assessment 2021 and/or Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

Choice of method, C stock change factors, and activity data

When a stand of trees reaches the predetermined minimum width, size, and crown cover in the forest definition, the NFI measures the stand. Estimates of the CSC in this category are

based on the same method as for the category forest land remaining forest land (see section 6.4.1).

Conversion of grassland to forest land results in an instant loss of grass biomass; loss of 3.995 tC ha<sup>-1</sup> for the boreal climate, 3.055 tC ha<sup>-1</sup> for the cool temperate dry climate, and 6.392 tC ha<sup>-1</sup> for the cool temperate moist climate in the first year of conversion. This is in accordance with the default Tier 1 methodology in the IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4, with a herbaceous biomass factor of 0.47 tC (t d.m.)<sup>-1</sup>.

Conversion of cropland to forest land results in instant annual crop biomass loss of 4.7 tC ha<sup>-1</sup> in the first year of conversion. This is in accordance with default Tier 1 methodology in the IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9, with a herbaceous biomass factor of 0.47 tC (t d.m.)<sup>-1</sup>.

For tree living biomass, NFI data on individual trees are used. For grass and crop biomass, areas obtained through the NFI are used.

#### Assumptions/justification

Justification for using the IPCC 2019 Refinement for annual crop biomass losses are described under section 6.5.2.

##### 6.4.2.1.2 Dead organic matter (key category)

The sink/source category dead organic matter on land converted from extensive and intensive grassland, settlement, cropland, and unmanaged wetland to forest land are identified as key categories for Level assessment 1990, Level assessment 2021 and/or Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

### Choice of method

A Tier 1 method estimates C changes in dead organic matter (DOM) for land converted to forest land. The method is spatially explicit, as it is applied to each NFI plot individually. Default IPCC reference C stocks for litter and deadwood are used (IPCC 2019), with added stocks from the fine woody litter fraction (Canadian NFI ground plots and the Canadian Forest Ecosystem Carbon Database ([https://nfi.nfis.org/en/ground\\_plot](https://nfi.nfis.org/en/ground_plot)), (<https://cfs.nrcan.gc.ca/publications?id=25626>)), as specified in IPCC 2006 Guidelines. Reference C stocks are selected according to the default IPCC climate region, FAO ecological zone (see section 6.3.2), and dominant tree species (deciduous or coniferous) as relevant for any NFI plot. The method is described in detail by Bárcena et al. (2021), and an overview is given here.

### Carbon stock change factors

The combination of IPCC climate regions with FAO ecological zones and dominant tree species (deciduous or conifers) produces 18 ecological-climatic zones for forest land in Norway, each with its unique reference C stock for the litter and dead wood pools. Rates of accumulation (annual CSC) are calculated assuming that DOM reference stocks (by 18 zones) accumulate over 20 years (default period) (see Table 6.21). A full overview of all possible DOM carbon stock values for ecological climate zones in Norway can be found in Bárcena et al. (2021). Table 6.21 presents the carbon stock change rates for land converted to forest land currently found in Norway.

**Table 6.21 Annual carbon stock change rates (t C ha<sup>-1</sup> yr<sup>-1</sup>) for land converted to forest land.**

| Ecological climate zones                    | Litter (tC ha <sup>-1</sup> yr <sup>-1</sup> ) |          | Dead wood (tC ha <sup>-1</sup> yr <sup>-1</sup> ) |          |
|---------------------------------------------|------------------------------------------------|----------|---------------------------------------------------|----------|
|                                             | deciduous                                      | conifers | deciduous                                         | conifers |
| <b>Boreal Moist Coniferous Forest</b>       | 1.05                                           | 2.1      | 0.82                                              | 1.11     |
| <b>Cool Temperate Moist Mountain System</b> | 0.3                                            | 0.4      | 1.06                                              | 2.405    |
| <b>Cool Temperate Oceanic Forest</b>        | 0.3                                            | 0.35     | 1.84                                              | 1.84     |
| <b>Cool Temperate Continental Forest</b>    | 1.35                                           | 3.5      | 1.18                                              | 1.105    |

### Activity data

The total area of land converted to forest land was estimated by using NFI data. The CSC rates (Table 6.21) are multiplied by the representative NFI plot area for a given land-use conversion. Interpolation, extrapolation, and aggregation follow, providing yearly national values.

#### 6.4.2.1.3 Mineral soils

##### Choice of method, C stock change factors, and activity data

A Tier 1 method was used based on i) a national soil class map, ii) default IPCC climate regions, iii) IPCC default reference stocks for mineral soil (IPCC 2019), and iv) IPCC default stock change factors (SCF's) (IPCC 2019). The resulting CSC rates are multiplied by the area pertaining to each land-use change, represented by areas of individual NFI plots. The method is described in detail by Bárcena et al. (2021), and an overview is given here.

Two legacy soil maps were combined with ongoing agricultural soil classification (primarily agriculture and intensive grassland areas) to identify soil classes (classes are more detailed than the overall categorization as “mineral soil”) for the entire land area (see section 6.3.3). For the land area, this resulted in a map with soil classes (large polygons), each characterized by a combination of specific soil types (where specific soil types refer to a classification as typically found in modern soil taxonomy). To estimate a given NFI plot's reference C stock (SOCREF), the mapped soil class in the NFI plot location was combined with the relevant IPCC default SOCREF (IPCC 2019) in the relevant IPCC climate region. When the mapped soil class was a combination of several specific soil types (in a taxonomic sense), the resulting SOCREF was found through a weighted average (of IPCC default SOCREF's) using the information of the specific soil type distribution given in the legacy maps. A SOCREF represents the SOC stock prior to management. Annual CSC rates are calculated by dividing the difference in two soil carbon equilibrium stocks (SOCEQ) by 20 (default period for land use conversions to move from one equilibrium to another). For a given land use, SOCEQ was found by multiplying the SOCREF with the stock change factors (SCF's). Each SCF is a product of three factors; a factor for land use (FLU), a factor for management regimes (FMG), and a factor for nutrient input (FI). Each of these factors can take on a number of different values. Default IPCC SCF's are used. Thus, annual CSC rates depend on mapped specific soil type distribution/soil class, IPCC climate region, and land-use specific SCF's. Each estimated CSC rate can be considered fairly unique as it depends on location, climate and the specific land-use conversion. Table 6.22 presents the national mean CSC rates for land uses converted to forest land and for different climate regions. No CSC occurs for wetlands and extensive grasslands converted to forest land on mineral soil due to common SCF (SCF=1).

The Tier 1 methodology (IPCC 2006; IPCC 2019) for mineral soil C utilizes the equation:  $2.25 \Delta SOC = (SOC_0 - SOC_0 - T)/D$  (see description in section 6.5.1.1), where  $SOC = \sum (SOCREF \cdot FLU \cdot FMG \cdot FI \cdot A)$ , SOCREF = the reference carbon stock (tonnes C ha<sup>-1</sup>), FLU = stock change factor for land-use systems or sub-system for a particular land-use, FMG = stock change factor for management regime, FI = stock change factor for the input of organic matter, and A = land area of the stratum being estimated.



| <b>Table 6.22 Annual mineral soil carbon stock change rates (mean <math>\pm</math> standard deviation in t C ha<sup>-1</sup> yr<sup>-1</sup>) for land converted to forest land (1990 – 2021)</b> |                   |                      |                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|----------------------|-----------------|
| <b>IPCC climate region</b>                                                                                                                                                                        | Cropland          | Intensive Grassland  | Settlements     |
| <b>Cool Temperate Moist</b>                                                                                                                                                                       | 0.669 $\pm$ 0.088 | -0.0752 $\pm$ 0.0067 | 0.07 $\pm$ 0.18 |

#### 6.4.2.1.4 Drained organic soils

For land converted to forest land on organic soils, we used a Tier 1 methodology, applying the default emission factor of 2.6 t C ha<sup>-1</sup> for the temperate zone as listed in the IPCC 2013 Wetlands supplement. We assumed that organic soils in areas with previous land-use of intensive grassland, cropland, wetlands, and settlements are drained. The activity data (areas) for organic soils on land converted to forest land was derived from the NFI.

#### 6.4.2.2 *Uncertainties and time-series consistency*

Generally, the uncertainties related to emission estimates for all sinks/sources were rather large, partly due to the uncertainty of the area estimate. Uncertainties are shown in Table 6.3 for living biomass and DOM and in Table 6.4 for mineral soil and drained organic soils.

The time-series were consistently estimated.

#### 6.4.2.3 *QA/QC and verification*

The internal QA/QC plan was completed as relevant for all source categories under land converted to forest land. In 2021, external quality assurance was carried out for the Tier 1 method for mineral soil and DOM (applies to all land-use conversions on mineral soil areas and for the soil and DOM pools). The Tier 1 method for mineral soil CSC estimates was further supplemented by a more detailed method (a subdivision of area classes) for settlement. This supplement to the method was sent to external QA in 2021.

#### 6.4.2.4 *Recalculations*

For all sources, changes have occurred in the last four years due to updated area extrapolation.

Some reclassifications of the plots (whole and split) in the database occur, which can cause recalculations for the whole time series.

See chapter 10.2.4 for details.

#### 6.4.2.5 *Planned improvements*

Living biomass, dead organic matter, mineral soils, and drained organic soils

No planned improvements.

#### 6.4.3 **Completeness**

The reporting of emissions and removals from forest land is complete.

### 6.5 Cropland – 4B

Cropland covers about 3% of the area of Norway. Agricultural cropland in Norway includes annual crops, temporary grass leys, and horticulture. In 2021, most of the area for agriculture was used for annual crops, primarily consisting of grass leys (61.5%) used as forage or green manure, cereals (37%) and a smaller area with root crops (1.5%), where potatoes and rutabagas are the most important crops (Berit Bjørlo - Statistics Norway. Personal communication, 2022).

Consequently, carbon is not stored for long time intervals in aboveground biomass. An exception is horticultural crops, where fruit trees can store large amounts of C. However, the area of perennial woody crops is a small fraction of the cropland area (approximately 0.2%).

Substantial amounts of C reside in the soil, affected by agricultural management practices such as tillage, crop residue input and organic manure application (Paustian et al. 2000). Dead organic matter is not an important source category for cropland in Norway since agroforestry systems are uncommon. This is except for forest land converted to cropland, where emissions from DOM are reported. Over the time series, the total cropland area has decreased nationally, despite the fact that conversion to cropland also occurs, primarily from forest land but also from wetlands on organic soils. CO<sub>2</sub> emissions from living biomass, DOM, mineral and organic soils on croplands are reported in CRF Table 4.B as described below, and CH<sub>4</sub> emissions from organic soils on croplands are reported in CRF Table 4(II) as described in section 6.12.

#### 6.5.1 **Cropland remaining cropland, 4B1**

The following emission sources were reported under cropland remaining cropland: C stock changes (CSC) in living biomass of perennial horticultural crops (fruit trees), C emission from mineral soils due to agricultural management (crop rotations, C inputs, and tillage) and C emission caused by the cultivation of organic soils. By far, the vast majority of emissions are caused by the cultivation of organic soils. Both minor net C gains and losses

are reported for living biomass, while a slightly increasing trend in CO<sub>2</sub> uptake is observed for mineral soils.

#### 6.5.1.1 *Methodological issues*

Annual changes in C stocks on cropland remaining cropland (C<sub>CC</sub>) can be estimated as the sum of changes in living biomass (C<sub>LB</sub>) and soils (C<sub>SO</sub>) by  $\Delta C_{CC} = \Delta C_{LB} + \Delta C_{SO}$ . Norway applies the Tier 1 steady state assumptions for dead organic matter because agroforestry is generally not practised. Thus, the agricultural systems have small amounts of dead organic matter. Living biomass is reported for fruit trees, and emissions from soils are reported for mineral soils and organic soils.

##### 6.5.1.1.1 Living biomass

Changes in C in living biomass are only considered for perennial woody crops, i.e., fruit trees. Perennial berry bushes are not considered due to the small area of approximately 300 ha (Borgen & Hysten 2013). Orchards may be felled but are considered to remain cropland. It is likely that orchards are replanted with fruit trees but may be converted to annual crops, leys, or vegetables in some instances. Annual changes in the area of fruit trees fluctuate, leading to both net emissions and removals during the inventory period. However, C stock changes are relatively small.

#### Choice of method, emission factors, and activity data

Due to a general lack of national data on biomass and carbon content in Norwegian fruit trees, we apply the Tier 1 Gain-Loss method. In the default method, the change in C stock in living biomass ( $\Delta C_{LB}$ ) is equal to the absolute C gain ( $\Delta C_G$ ) minus the absolute C loss (C<sub>L</sub>) by  $\Delta C_{LB} = \Delta C_G - \Delta C_L$  (IPCC 2019 Refinement, Equation 2.7).

Statistics Norway collects data every year on the areas of fruit trees (apples, plums, cherries, sweet cherries, and pears). The data are available from 1990 to 2021 and are collected as a questionnaire survey to provide information about yields and production area. The area of fruit trees has generally decreased since 1990. Norway uses the Tier 1 default value from IPCC (2019) for the above-ground biomass accumulation rate in the temperate zone, which is 0.43 t C ha<sup>-1</sup> yr<sup>-1</sup>, and the corresponding value for maximum above-ground biomass C stock at harvest, which is 8.5 t C ha<sup>-1</sup>. The default harvest/maturity cycle is 20 years. The yearly increase or decrease in areas is accounted for from 1990 to the current reporting year, based on the annual SSB fruit tree area estimates. The age class distribution in the area with fruit trees is taken into account, and the methodology is based on a number of assumptions: i) Prior to 1990, the fruit tree area remains constant; ii) Maximum tree age is 20 years, representing the age of harvest; iii) The age of the trees is evenly distributed over the area prior to 1990 in 1-year increment age-classes; iv) The age

class distribution in 1990 and later changes as follows: The area representing the age class of 21-year-old trees are assumed removed (biomass loss,  $8.5 \text{ t C ha}^{-1}$ ) and replaced with the age class of 1-year-old trees (biomass gain,  $0.43 \text{ t C ha}^{-1} \text{ yr}^{-1}$ ). If there is a net increase in area (SSB) in a given year, the increase is allocated to the age class of 1-year-old trees (biomass gain). Suppose there is a net decrease in area (SSB) in a given year. In that case, areas representing the oldest age classes are reduced first (20 years age class before the 19-year age class, 19-year age class before the 18-year age class, etc.); the biomasses are assumed to be lost when areas of a given age class are reduced reflect the biomass accumulated to the relevant age (e.g.  $8.5 \text{ t C ha}^{-1}$ ,  $8.07 \text{ t C ha}^{-1}$ ,  $7.64 \text{ t C ha}^{-1}$ , etc.).

#### Assumptions/justification

Given the default method, we assume that: 1) there is a uniform age-class distribution for the total perennial living biomass for each age-class in the year 1989 (base year), 2) all orchard trees are less than  $\leq 20$  years old, and that above-ground biomass accumulates at the default rate, and 3) all felled orchards are plantations with mature trees around 21 years of age and have the default maximum above-ground carbon stock at harvest. 4) always new 1-year-old orchards are planted, replacing the removed 21-year-old orchards.

These assumptions may not completely represent Norway, as recommendations to growers are to harvest apples, plums, and sweet cherry trees after 20 years and pear trees after 25 years (Hovland 2020). However, the activity data does not provide information on the age of the plantations when felled.

#### 6.5.1.1.2 Dead organic matter

The Tier 1 method was used assuming no C stock change in the dead organic matter pool on cropland remaining cropland, and the notation key NO is reported in the CRF tables.

#### 6.5.1.1.3 Mineral soils

Most (roughly 94%) of agricultural production occurs on mineral soils. Carbon inputs from animal manure have slightly increased in some parts of the country resulting in C uptake, i.e., positive C stock changes.

#### Choice of method

The Tier 2 method estimates annual changes in soil organic C (SOC) according to IPCC 2006 Guidelines, Equation 2.25, where the annual change in SOC is given by  $\Delta \text{SOC} = (\text{SOC}_0 - \text{SOC}_{0-T})/D$ , where D is the time dependency of the stock change factors.  $\text{SOC}_0$  is the stock in the last year of the inventory period, and  $\text{SOC}_{0-T}$  is the C stock at the beginning of the inventory period. The default value for D was adjusted to 30 years, given the slower decomposition rates under the cool temperate climate in Norway (Borgen et al. 2012). The

SOC stock is calculated as the product of the soil C reference stock ( $SOC_{REF}$ ), the stock change factor for a given management and climate regime (F), and the associated area (A) given by  $SOC = SOC_{REF} \times F \times A$ . We used the reference stock and stock change factors estimated by the Introductory Carbon Balance Model (ICBM) in a study where  $CO_2$  emissions were estimated for Norwegian cropland from 1999 - 2009 (Borgen et al. 2012). The ICBM is an ecosystem model from Sweden developed by Andrén et al. (2004). Soil C reference stocks were estimated for 31 different climatic zones (agrozones), assuming that continuous grass ley cropping was the reference condition. Stock change factors were calculated for eight rotations with and without manure application (i.e., resulting in  $2 \times 8 = 16$  management rotations) for each of the 31 agrozones, resulting in a total of 496 stock change factors. The rotations were 1:2 ley-grain, 1:1 ley-grain, 2:1 ley-grain, continuous grain (with and without straw removal), continuous ley, 1:2 roots-grain, and 1:2 roots-ley, where 1:2 means 1 year of root crops and 2 years of ley and so on. Further details of the model application and the stratification are given in Borgen et al. (2012). We calculated annual SOC changes per agrozone and summarized the CSC for the whole country.

#### Stock change factors and soil C reference stocks

The stock change factors represent the annual response of SOC to a change in management from a reference condition and can be calculated as  $F = SOC/SOC_{REF}$ . The soil C reference stocks were estimated by solving the ICBM model for steady-state conditions using C input equal to continuous grass ley cropping with a moderate manure application (0.5 Mg C per hectare per year) for each Norwegian agrozone. Average national stock change factors for the 16 crop rotations and average soil C reference stocks per agrozone are listed in Borgen et al. (2012).

#### Activity data

Area per crop type and manure statistics are collected annually from the Norwegian Agricultural Authority (NAA) to determine the area under each of the 16 crop rotations. Norway was divided into 31 agrozones based on a combination of counties and climate-based production zones (defined by NAA for subsidy application) as described in Borgen et al. (2012), and the statistics are given for each agrozone. Within each agrozone, the relation between the major crops of small grains (cereal and oilseeds), root crops (potato and rutabaga), and grass ley were used to allocate the areas under each of the eight crop rotations. The activity data of the quantity of manure applied to fields with annual crops per county were received from Statistics Norway. These data correspond to the data used for estimating non- $CO_2$  emissions related to animal manure for the Agricultural sector. As it is not possible to differentiate between manure applied to perennial grass leys on cropland from the grass leys on grassland (intensive or extensive), we only include the manure

applied to annual crops (i.e., all manure applied on cropland). Further information on assumptions regarding manure distribution is given in Borgen et al. (2012). The areas of cropland remaining cropland on mineral soils were estimated by the NFI for the whole time series.

#### Assumptions

The IPCC Tier 1 and 2 methods assume that the SOC change resulting from a change in management is linear between two steady states. Soil C changes are likely to be more dynamic, and it has been argued that the lower-tier methods overestimate net C sequestration, particularly where the soil was not in a steady state at the beginning of the inventory (Sanderman & Baldock 2010). However, at present, this method provides an acceptable approximation.

##### 6.5.1.1.4 Organic soils (key category)

Organic soils make the largest contribution of CO<sub>2</sub> emissions within the source categories for cropland. It was identified as a key category for Level assessment 1990, 2021 and Trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6). The Norwegian definition of organic soils for cropland is described in detail in section 6.2.3, Table 6.10.

#### Choice of method and emission factor

A Tier 1 method is used for the estimation of CO<sub>2</sub> emissions from organic soils on cropland, where the IPCC Tier 1 method necessitates the use of the default emission factor (EF) to be multiplied by the area (A) of organically cultivated soil according to IPCC 2006 Guidelines, Equation 2.26  $C_{\text{LOSS}} = A \times \text{EF}$ . Since the 2015 submission, Norway has used the default EFs from the IPCC 2013 Wetlands supplement for boreal/temperate cropland of 7.9 t CO<sub>2</sub> C ha<sup>-1</sup> yr<sup>-1</sup>.

#### Activity data

The area of agricultural organic soil was estimated as described in section 6.3.3.

##### **6.5.1.2 Uncertainties and time-series consistency**

The uncertainty estimation is related to the tier level of the methodology used for each sink/source category and land-use category. For cropland remaining cropland, Tier 1 and 2 methods were applied. The IPCC 2006 Guidelines include uncertainty estimates for default emission/removal factors.

For cropland remaining cropland, the total uncertainty is equal to the propagation of the uncertainty related to the living biomass ( $U_{CC\_LB}$ ), mineral soils ( $U_{CC\_MS}$ ), and organic soils ( $U_{CC\_OS}$ ) and is given by

$$U_{CC} = \sqrt{U_{CC\_LB}^2 + U_{CC\_MS}^2 + U_{CC\_OS}^2}.$$

For each source category, the uncertainty is a combination of the uncertainties related to the emission factors  $U_{EF}$  and the activity data  $U_A$ , which is the uncertainty used in the Key Category Analysis (KCA) and can be calculated by

$$U = \sqrt{U_A^2 + U_{EF}^2}.$$

The uncertainty of the activity data may include errors in census returns and differences in the definition between agencies, sampling design, and interpretation of samples. The activity data used under cropland, i.e., areas per crop types and manure production, were collected through the subsidy application scheme administrated by NAA and compiled by SSB. The data is based on a total national census. The NAA performs quality control on 5% of farms to determine if areas are provided correctly. These sample checks show very few errors. The area reported is based on a factor value multiplied by the last year's area. Thus errors in previous years may accumulate. However, according to expert judgment given by SSB, the uncertainty of the activity data is estimated to be approximately 0%.

#### 6.5.1.2.1 Living biomass

Sources of uncertainty for the Tier 1 method for living biomass include the degree of accuracy in the C accumulation and loss rates and the land-use activity data. The 2019 IPCC Refinement default uncertainty error for aboveground woody biomass accumulation in the temperate climate is  $\pm 46\%$ . SSB estimated the uncertainty of the activity data as approximately 0%. The areas of orchards are used directly from the NAA/SSB data and are unrelated to the NFI database. Therefore, the uncertainty of the C biomass accumulation per unit area is equal to the total uncertainty of the C changes in living biomass on cropland remaining cropland.

#### 6.5.1.2.2 Mineral and organic soils

Uncertainty related to emission estimates from soils on cropland can currently only be precisely quantified for the area estimates based on the NFI data. For the area of mineral soils on cropland remaining cropland, the uncertainty estimate was reported at 7% (Table 6.4). For the mineral soil estimates, the areas per crop type used to determine the areas under individual crop rotations were collected and compiled by the Norwegian Agriculture Authority (NAA) and Statistics Norway (SSB). Since the data are based on a census, it was

assumed not to increase the area uncertainty. The uncertainties related to the stock change factors estimated by ICBM were estimated at  $\pm 50\%$  based on expert judgment. For organic soils, the area uncertainty was 24%, and default uncertainties were used from the guidelines. The total uncertainty for CO<sub>2</sub> emissions from drained organic soils on cropland was 30% (Table 6.4).

#### **6.5.1.3 QA/QC and verification**

The standard Tier 1 QC procedures described in section 6.1.6 were performed for both living biomass and soil estimates. No external QA was performed on the Tier 1 method for estimating C changes in living biomass stocks in orchard trees. Before the 2013 submission, when the Tier 2 for mineral soils on cropland remaining cropland was implemented, quality assurance was done through the standardized peer-review process.

#### **6.5.1.4 Recalculations**

The CSC for cropland remaining cropland on mineral soil is calculated concerning the carbon stock estimate 30 years before. This reference period was fixed, but from this year, a floating reference (30 years before) is used, resulting in recalculations for the last two years. In addition, an update in extrapolated areas resulted in changes in mineral and organic soil emissions.

See chapter 10.2.4 for details.

#### **6.5.1.5 Planned improvements**

Living biomass, dead organic matter, mineral soils, and organic soils

There are no planned improvements.

### **6.5.2 Land converted to cropland, 4B2**

Emissions and removals on land converted to cropland are reported from the C stock changes in living biomass, dead organic matter, mineral soils, and organic soils. C stock changes in dead organic matter on other land-use conversions than those to and from forest land can be considered insignificant and are reported with the notation key NO in the CRF tables.

Land conversion to cropland primarily occurs from forest land and less from grassland, wetlands, and settlements. There were no conversions from other land to cropland during the inventory period, and NO is reported in the CRF Table 4.B. Conversion of land to cropland usually results in a net carbon loss from living biomass and soils to the atmosphere as stated at the IPCC 2006 Guidelines.



### 6.5.2.1 *Methodological issues*

#### 6.5.2.1.1 Living biomass (key category)

The sink/source category living biomass on forest land converted to cropland is identified as a key category for Level assessment 2021 and Trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6).

#### Choice of method, C stock change factors, and activity data

For forest land and wetlands converted to cropland, we used the Tier 3 method described for forest land to estimate C stock changes in living tree biomass (see section 6.4.1). The category grassland converted to cropland is very small. Nonetheless, as of 2007, woody biomass changes are also monitored on grassland. No change in the woody living biomass was observed for those sample plots converted from grassland to cropland.

Conversions of grassland to cropland result in instant grass biomass loss of 3.995 tC ha<sup>-1</sup> for boreal climate, 3.055 tC ha<sup>-1</sup> for cool temperate dry climate, and 6.392 tC ha<sup>-1</sup> for cool temperate moist climate in the first year of conversion in accordance with the default Tier 1 methodology in IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4, with a herbaceous biomass factor of 0.47 tC (t d.m.)<sup>-1</sup>.

All other conversions of land to cropland result in instant annual crop biomass gains of 4.7 tC ha<sup>-1</sup> in the first year of conversion in accordance with default Tier 1 methodology in IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9, with a herbaceous biomass factor of 0.47 tC (t d.m.)<sup>-1</sup>.

#### Assumptions/justification

Annual crop biomass gains/losses of 4.7 tC ha<sup>-1</sup> provided by the IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9 provides an update to the IPCC 2006 Guidelines, Vol. 4, Ch. 5, Table 5.9. This is likely a correction as conflicting values within IPCC 2006 Guidelines suggest annual crop biomass gains of 5.0 tC ha<sup>-1</sup> in Table 5.9 and 4.7 tC ha<sup>-1</sup> crop biomass losses under section 6.3.1.2, Tier 1 pt. 2 (IPCC 2006).

#### 6.5.2.1.2 Dead organic matter (key category)

C stock changes in the dead organic matter (DOM) pool on forest land converted to cropland was identified as a key category for Level assessment 1990, Level assessment 2021, and Trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6).

#### Choice of method, C stock change factors, and activity data

DOM for forest land to cropland applies a similar Tier 1 methodology as for lands to forest land (section 6.4.2). The difference is that instead of DOM gains, there are DOM losses. Furthermore, the losses occur instantly (instant oxidation) within the first year of conversion instead of being distributed over 20 years. Table 6.23 presents the DOM carbon stock loss factors for forest land converted to cropland currently found in Norway.

| <b>Table 6.23 Instant DOM carbon stock loss (t C ha<sup>-1</sup>) for forest land converted to cropland.</b> |                                    |          |                                       |          |
|--------------------------------------------------------------------------------------------------------------|------------------------------------|----------|---------------------------------------|----------|
| <b>Ecological climate zones</b>                                                                              | <b>Litter (tC ha<sup>-1</sup>)</b> |          | <b>Dead wood (tC ha<sup>-1</sup>)</b> |          |
|                                                                                                              | deciduous                          | conifers | deciduous                             | conifers |
| <b>Cool Temperate Moist Mountain System</b>                                                                  | 6                                  | 8        | 21.2                                  | 48.1     |
| <b>Cool Temperate Oceanic Forest</b>                                                                         | 6                                  | 7        | 36.8                                  | 36.8     |
| <b>Cool Temperate Continental Forest</b>                                                                     | 27                                 | 70       | 23.6                                  | 22.1     |

For grassland, wetlands, and settlements converted to cropland, we used the Tier 1 method that assumes no C stock change in the DOM pool. Emissions are reported as NO.

#### 6.5.2.1.3 Mineral soils

##### Choice of method and C stock change factors

The same Tier 1 methodology applied for lands converted to forest land is also applied here (see section 6.4.2). The national mean mineral soil CSC rate from 1990 - 2021 for lands converted to cropland can be found in Table 6.24.

| <b>Table 6.24 Annual mineral soil carbon stock change rates (mean ± standard deviation in t C ha<sup>-1</sup> yr<sup>-1</sup>) for lands converted to cropland (1990 – 2021).</b> |                |                     |                     |              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|---------------------|---------------------|--------------|
| <b>IPCC climate region</b>                                                                                                                                                        | Forest land    | Extensive Grassland | Intensive Grassland | Settlements  |
| <b>Cool Temperate Moist</b>                                                                                                                                                       | -0.705 ± 0.086 | -0.787              | -0.661 ± 0.071      | -0.23 ± 0.11 |

#### Activity data

Areas of land converted to cropland on mineral soils were estimated using the NFI data and the 1990 baseline map of soil types.

#### 6.5.2.1.4 Organic soils (key category)

Forest land and wetlands converted to cropland on organic soils are identified as key categories for Level assessment 1990, Level assessment 2021, and/or Trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6).

#### Choice of method and emission factor

We used a Tier 1 method to estimate emissions from organic soils on land converted to croplands. The default emission factor of  $7.9 \text{ t C ha}^{-1} \text{ yr}^{-1}$  was applied, assuming similar emissions as for cropland remaining cropland, regardless of the previous land use.

#### 6.5.2.1.4.1 Activity data

All areas were derived as described in section 6.3.3.

#### **6.5.2.2 Uncertainties and times-series consistency**

Uncertainties were estimated as described in section 6.1.3 and shown as total aggregated uncertainty ( $U_{\text{total}}$ ) based on the uncertainties of the C stock change (CSC) per hectare and the area estimates for living biomass and DOM (Table 6.3), and mineral and organic soils (Table 6.4)

#### **6.5.2.3 QA/QC and verification**

The Tier 1 QC procedures were performed during the estimation of C stock changes for land converted to cropland.

#### **6.5.2.4 Recalculations**

Dead organic matter, mineral soil and living biomass have changed for the last four common years due to updated extrapolation. Most of the changes come from forest land to cropland conversions.

See chapter 10.2.4. for details.

#### **6.5.2.5 Planned improvements**

#### Living biomass, dead organic matter, mineral soils, and organic soils

No planned improvements.

### **6.5.3 Completeness**

The reporting of emissions from cropland is complete.

## 6.6 Grassland – 4C

Grasslands cover about 35% of the area of Norway. According to the IPCC 2006 Guidelines, grasslands are defined as grass areas with insufficient woody biomass to be classified as forest land that is not considered cropland. It may also include shrublands with perennial woody biomass. There are five types of grasslands identified in Norway, which are further categorized into intensive or extensive grasslands for GHG reporting (Table 6.25):

### Intensive grassland

Closed pastures (Innmarksbeite) represented about 1.8% of the grassland area in Norway over the period 2015 - 2019. They are semi-natural areas covered by a minimum of 50% grasses or grazable herbs enclosed by a fence or a natural barrier and can locally include some areas meeting the forest definition (see box “Forested area in closed pastures” at the end of this section). For these areas, the topography (e.g., steepness or surface roughness) or the presence of trees prevent any mechanical harvest or species improvement; fertilization, however, seems to occur regularly in some areas. Closed pasture areas are directly estimated via the subsidy application scheme as they support a rather intensive grazing system for cattle and sheep.

No-till cultivated grass pastures (Overflatedyrka eng) represented only 0.2% of the grassland area in Norway over the period 2015 -2019. They are characterized by shallow and rocky soils unsuitable for mechanical ploughing that may be cultivated intensively via fertilization, mechanical harvesting, and improved species. No-till cultivated grass pasture areas are directly estimated via the subsidy application scheme as they support an intensive grass production system.

### Extensive grassland

Other non-wooded land (Snaumark) represented  $\geq 80.9\%$  of the grassland area in Norway over the period 2015 - 2019. This is land on mineral soil with no trees, or less than 5% crown cover, or less than 10% crown cover if a combination of shrubs, bushes, and trees. These are all the remaining natural areas with a minimum of 50% ground vegetation cover, as recorded in the NFI. Grazing by cattle, sheep, goats, horses or reindeer can occur.

Other wooded land (annet tresatt areal) represented about 15.3% of the grassland area in Norway over the period 2015 - 2019. These are areas with a crown cover of

5 to 10% for trees higher than 5m or areas where the crown cover of trees and shrubs together has a cover of more than 10%. Shrub vegetation includes perennial shrubs and trees that are over 0.5 m high but are unable to reach a height of 5 m in the site. This area type will occur primarily on very low-productive land (lands with shallow soils) and lands in a transitional phase on areas that are growing back to forest. Other wooded land can occur in areas with a ground vegetation cover < 50%, as recorded in the NFI and may therefore be associated with widely varying soil carbon stocks. Other wooded land does not meet the forest definition and classifies as extensive grassland.

Coastal heath (Lynghelandskapet) represented about 1.7% of the grassland area in Norway between 2015 - 2019. Coastal heath are coastal shrublands with high proportions of perennial woody biomass. Heath vegetation can be considered a transitional stage in succession from grass-dominated grassland to woodland. While succession tends to drive this change in one direction towards woodland, management by grazing and burning, and fertilization tends to reverse the trend. Excessive burning, grazing, and fertilization may change heath vegetation into grass-dominated grassland (Legg 1995; Nilsen 2004). The NFI operationally classifies coastal heath as areas in the lowlands along the coast from Aust-Agder to Finnmark, characterized by a specific plant community. While tree and shrub vegetation can occur locally, they would never meet the definition of "other wooded land". More specifically, coastal heath is characterized by the absence of a tree layer and the presence of an atypical shrub layer made of juniper, dwarf birch, eared willow, as well as birch, rowan, pine, and spruce at the beginning of the overgrowth. Common heather (*Calluna vulgaris*) dominates, but other heather species, grass, herbs and ferns can also occur. Coastal heath often occurs in a mosaic with rocks; these areas must have more than 50% ground vegetation coverage as recorded by the NFI (of the defining vegetation types) to classify as coastal heath. Land classified as coastal heath is limited by elevation, which decreases with increasing latitude as 200 m for Aust-Agder, Vest-Agder and Rogaland; 150 m for Hordaland and Sogn og Fjordane; 100 m for Møre og Romsdal, Sør-Trøndelag and Nord-Trøndelag; and 50 m for Nordland, Troms, and Finnmark. Coastal heath is classified as extensive grassland. Coastal heath is, by definition, on mineral soil.

Both extensive and intensive grassland areas are estimated from NFI plots. Statistics Norway provides information about the proportion of No-till cultivated pastures vs closed pastures within the intensive grassland category based on data collected through the

subsidy application scheme. Subsidy support is given to grazed or harvested areas at least once a year. Extensive grasslands are only found on mineral soil.

**Table 6.25 Identified Grassland types.**

| Grassland type                    | Grassland area (2015 – 2019) | Mechanically ploughable | Mechanically harvestable | Area enclosed | Shrubland |
|-----------------------------------|------------------------------|-------------------------|--------------------------|---------------|-----------|
| <b>Intensive grassland</b>        |                              |                         |                          |               |           |
| Closed pastures                   | 1.8%                         | No                      | No                       | Yes           | No        |
| No-till cultivated grass pastures | 0.2%                         | No                      | Yes                      | -             | No        |
| <b>Extensive grassland</b>        |                              |                         |                          |               |           |
| Other non-wooded land             | ≥ 80.9%                      | No                      | No                       | No            | -         |
| Other wooded land                 | 15.3%                        | No                      | No                       | No            | Yes       |
| Coastal Heath                     | 1.7%                         | No                      | No                       | No            | Yes*      |

Yes and No: correspond to the requirement to meet the grassland category definition. \* yes, but atypical.

-: the dash symbolizes "No requirement" and therefore can be understood as "can occur".

### Box 2 - Forested area in closed pastures

Between 2015 and 2019, 72.3 kha forested grasslands occurred in closed pasture, representing 31% of intensive grasslands. These NFI plots have sufficient tree cover to meet at least the minimum threshold of forest in Norway (i.e., greater than 10% tree cover with the potential to reach 5 m height on a minimum area of 0.1 ha), but grazing, and not wood harvesting, is the dominant land use activity. Trees are either distributed in groups, can be widely spaced, or are scattered across the grassland area. Forested grasslands are categorized as grasslands due to the determining effects of grazing pressure and grazing land management, which hinder tree regeneration and maintains their dominant grassland character and ecology. There is evidence that the tree biomass sequestered in forested grasslands is small compared to the sequestration in forest land remaining forest land. From 1990 - 2021, the cumulative sum of net living biomass sequestered on forested grassland remaining forested grassland plots is approximately 0.2% (325 kt C) of the net living biomass sequestration in forest land remaining forest land. There is currently not enough empirical data or scientific literature to adequately describe the C dynamics of forested grasslands in Norway. Expert judgement hypothesises is that the C dynamics are an intermediate condition between that of fully stocked forest land and pure grassland, but where the grassland C dynamics are dominant. Given that the tree living biomass is accounted for and the number of plots are few, the overall impact on the LULUCF GHG inventory is considered small.

### 6.6.1 Grassland remaining grassland, 4C1

For grassland remaining grassland, C stock changes (CSC) are reported for living biomass and mineral and organic soils. Both extensive grassland remaining extensive grassland and intensive grassland remaining intensive grassland are key categories concerning living biomass, while only intensive grassland remaining intensive grassland is a key category for mineral soil.

#### 6.6.1.1 Methodological issues

Emissions due to changes in dead organic matter are assumed negligible for this category because little dead wood and litter are generated in grassland systems. Assuming that CSC in DOM is in a steady state condition is in accordance with the IPCC 2006 Guidelines, and the notation key NO is used in the CRF tables.

#### 6.6.1.1.1 Living biomass (key category)

The sink/source category living biomass on intensive grassland remaining intensive grassland is identified as a key category for Level assessment of 1990 according to Approach 2 key category analysis (see Table 6.6).

##### Choice of method

A Tier 2 method was used. Living biomass on grassland has been measured in the NFI since 2007. The average CSC (gains and losses) per hectare and year was calculated based on the sample plots measured since 2007. The C gain and loss averages were then multiplied by the area of grassland remaining grassland for the whole time series to obtain the total gain and loss estimates, respectively. This method was used on intensive and extensive grasslands.

#### 6.6.1.1.2 Mineral soils (key category)

Mineral soil on intensive grassland remaining intensive grassland is identified as a key category for Trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6).

##### Choice of method

For intensive grasslands, a default Tier 1 approach was used for estimating CO<sub>2</sub> emissions from intensive grassland remaining intensive grassland on mineral soils. The default IPCC methodology estimates soil C changes based on default stock change factors specific to management and climate regimes and soil C reference stocks specific to climate and soil type. The annual changes in SOC can be calculated as the difference between the SOC stock in the last year (SOC<sub>0</sub>) and the beginning (SOC<sub>0-T</sub>) of the inventory period (T) divided by the time dependency of the stock change factors (D = 20 years) and is given by

$$\Delta SOC = (SOC_0 - SOC_{0-T})/D \quad \text{Equation 2.25 (IPCC 2006).}$$

Following the example given in the IPCC 2006 Guidelines, page 2.35, first paragraph, this instruction would translate as the following:

From 1990 to 2010, SOC<sub>0-T</sub> is calculated for 1989 based on the assumption that SOC was at equilibrium before 1990.

$$\Delta SOC = \frac{SOC_0 (\text{year} = \text{current year}) - SOC_{0-T} (\text{year} = 1989)}{20 \text{ years}}$$

From 2010 onward, the year for estimating SOC<sub>0-T</sub> increased from 1990 by one year every new year.

$$\Delta SOC = \frac{SOC_0 (\text{year} = \text{current year}) - SOC_{0-T} (\text{year} = \text{current year} - 20)}{20 \text{ years}}$$



SOC stocks for any year of the inventory can be calculated as the product of the soil C reference stock ( $SOC_{REF}$ ), the stock change factors (SCF), and the area under a given management practice (A) according to

$$SOC = SOC_{REF} \times SCF \times A \quad \text{Equation 2.26 (IPCC 2006).}$$

The C reference stock is the soil C stock under the reference condition, which in the default method is native uncultivated soil. The reference stock is specific to climate zone and soil type.

Extensive grasslands remaining extensive grasslands also follow a Tier1 methodology. However, it is assumed that mineral soil carbon stock change does not occur (NO).

Conversions from intensive to extensive grasslands and from extensive to intensive grasslands occur. To estimate soil carbon changes, the Tier1 methodology used is the same as that applied for all land use changes on mineral soil, see section 6.3 and Bárcena et al. (2021). For these conversions, SCF for intensive and extensive grasslands are equal to 1.014 (weighted by areas of closed pasture and No-till cultivated, 90% and 10% respectively) and 1 respectively, and  $SOC_{REF}$  for specific NFI plots are acquired from the same database as for lands converted to grasslands; see below. Conversions from extensive to intensive grasslands are reported under “intensive grasslands remaining intensive grasslands”. Conversions from intensive to extensive grasslands are reported under “extensive grasslands remaining extensive grasslands”.

#### Activity data

The areas of intensive grasslands on mineral soil and extensive grasslands (Coastal Heath, Other wooded land with crown cover and 5-10% and Other non-wooded areas) are from the NFI. The area distribution between No-till and closed pastures (subcategories of intensive grasslands) was provided by Statistics Norway. These data were collected from farmers' applications for subsidies. Areas for both grassland types are given per farm unit. Because farmers may not always apply for subsidies, the area estimated by NFI is larger than that reported by SSB (Table 6.26). SSB data are therefore only used to access the relative importance of both grassland types. From 1990 to 1997, the No-till cultivated grass pastures only accounted for fertilized pastures, while from 1998 onward, it accounted for all types of no-till cultivated pastures. This resulted in 12.7% artificial increases in the concerned area between 1997 and 1998, indicating that about 87.3% of the No-till cultivated grass pastures are fertilized.

**Table 6.26 Areas (kha) of grassland remaining grassland on mineral soils in Norway from 1990 to 2021 from two different sources (NFI and SSB).**

| Year | Statistics Norway (SSB) |                             |       | NFI database        |                     |
|------|-------------------------|-----------------------------|-------|---------------------|---------------------|
|      | Intensive Grassland     |                             |       | Intensive Grassland | Extensive Grassland |
|      | Closed pastures         | No-till cultivated pastures | Total |                     |                     |
| 1990 | 88                      | 22                          | 109   | 222                 | 11285               |
| 1991 | 81                      | 27                          | 109   | 222                 | 11284               |
| 1992 | 85                      | 27                          | 112   | 221                 | 11284               |
| 1993 | 90                      | 27                          | 117   | 220                 | 11284               |
| 1994 | 94                      | 26                          | 120   | 220                 | 11283               |
| 1995 | 98                      | 26                          | 124   | 219                 | 11283               |
| 1996 | 101                     | 26                          | 127   | 218                 | 11282               |
| 1997 | 103                     | 27                          | 130   | 217                 | 11282               |
| 1998 | 108                     | 25                          | 133   | 216                 | 11281               |
| 1999 | 111                     | 29                          | 141   | 215                 | 11281               |
| 2000 | 122                     | 30                          | 151   | 213                 | 11281               |
| 2001 | 129                     | 29                          | 158   | 212                 | 11280               |
| 2002 | 132                     | 28                          | 161   | 211                 | 11279               |
| 2003 | 135                     | 28                          | 163   | 211                 | 11279               |
| 2004 | 137                     | 27                          | 164   | 210                 | 11278               |
| 2005 | 139                     | 27                          | 166   | 210                 | 11277               |
| 2006 | 142                     | 27                          | 169   | 209                 | 11277               |
| 2007 | 146                     | 26                          | 172   | 209                 | 11276               |
| 2008 | 149                     | 25                          | 175   | 207                 | 11274               |
| 2009 | 151                     | 24                          | 175   | 206                 | 11273               |
| 2010 | 152                     | 22                          | 175   | 205                 | 11271               |
| 2011 | 155                     | 21                          | 176   | 204                 | 11267               |
| 2012 | 156                     | 20                          | 177   | 202                 | 11263               |
| 2013 | 156                     | 20                          | 177   | 201                 | 11259               |
| 2014 | 156                     | 20                          | 176   | 200                 | 11255               |
| 2015 | 156                     | 20                          | 176   | 200                 | 11250               |
| 2016 | 156                     | 20                          | 176   | 200                 | 11247               |
| 2017 | 156                     | 20                          | 176   | 200                 | 11244               |
| 2018 | 161                     | 20                          | 181   | 201                 | 11241               |
| 2019 | 159                     | 20                          | 179   | 201                 | 11238               |

|             |     |    |     |     |       |
|-------------|-----|----|-----|-----|-------|
| <b>2020</b> | 158 | 21 | 178 | 202 | 11235 |
| <b>2021</b> | 156 | 21 | 177 | 202 | 11231 |

The intensive grassland areas per management type were stratified into eight regions (Figure 6-18). The area data from SSB (distribution between No-till and closed pasture) are available on a municipality level facilitating the stratification. Soil maps were collected to stratify the areas according to soil type and assign specific C reference stocks based on the soil type distribution within each region.

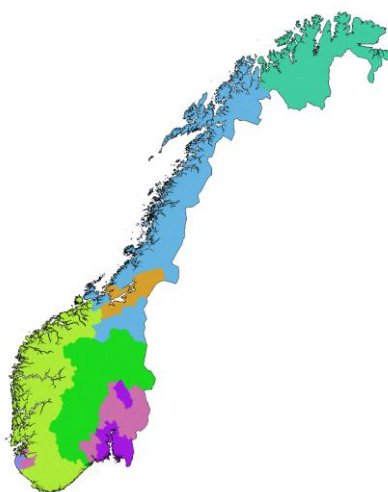


Figure 6-18 Eight regions of Norway were used to stratify grassland activity data for the Tier 1 application.

#### Stock change factors and soil C reference stocks

The general stock change factor **SCF** used in Equation 2.25 (IPCC 2006) to estimate the SOC stock at equilibrium under different types of intensive grassland is given by the following Equation:  $SCF = F_{LU} \times F_{MG} \times F_I$ , where  $F_{LU}$ ,  $F_{MG}$ , and  $F_I$ , represent partial stock change factors respectively for **1)** the land use system, **2)** the management regime, and **3)** the organic matter input to the soil. Default partial stock change factors are directly provided by the Tier 1 methodology in IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.2, simplified in Table 6.27.

**Table 6.27 Relative Carbon Stock Change factors (SCF) for grassland in a temperate/boreal climate regime**

| Factor | Level | IPCC default | Definition |
|--------|-------|--------------|------------|
|--------|-------|--------------|------------|

|                       |                     |      |                                                                                                                                                           |
|-----------------------|---------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>F<sub>LU</sub></b> | All                 | 1.00 | All grasslands                                                                                                                                            |
| <b>F<sub>MG</sub></b> | Non-degraded        | 1.00 | Non-degraded,<br>0 improvements*                                                                                                                          |
|                       | Moderately degraded | 0.95 | Moderately degraded, reduced loss of productivity overgrazed,<br>0 improvement*                                                                           |
|                       | Severely degraded†  | 0.70 | Major long-term loss of productivity and vegetation cover due to severe mechanical damage to the vegetation and/or severe soil erosion,<br>0 improvement* |
|                       | Improved            | 1.14 | Non-degraded,<br>moderate grazing pressure,<br>1 improvement*                                                                                             |
| <b>F<sub>I</sub></b>  | Medium input        | 1.00 | 0 or 1 improvement*                                                                                                                                       |
|                       | High input          | 1.11 | ≥ 2 improvements*                                                                                                                                         |

Improvement\*: 1) fertilization, 2) species improvement, 3) irrigation†. †: negligible.

Parametrizing the Tier 1 procedure consists of determining the **F<sub>LU</sub>**, **F<sub>MG</sub>**, and **F<sub>I</sub>** combination for each intensive grassland category. For the land-use factor **F<sub>LU</sub>**, the situation is simple as it is fixed to (**F<sub>LU</sub>** = 1) for all types of intensive grassland. Determining the factors for management **F<sub>MG</sub>** and organic matter input **F<sub>I</sub>** for each intensive grassland category is primarily related to the number of three possible improvements received by these categories: 1) mineral fertilization, 2) species improvement, and 3) irrigation (Table 6.27). Then, it depends on the general degradation of the intensive grassland category due to grazing pressure.

As grassland irrigation is generally not practised in Norway and severe grassland degradation may only affect negligible areas (e.g., fence opening), we excluded these possibilities from determining the intensive grassland type stock change factors. Grazing pressure has an impact on the soil carbon stock. In Norwegian low alpine grasslands, Martinsen et al. (2011) showed that a sheep density of 25 animal km<sup>2</sup> would induce no change in the soil organic carbon storage (~ 5% increase). In contrast, a sheep density of 80 animal km<sup>2</sup> would induce a slight 16% decrease. In Norway, domestic grazing animals are largely dominated on average by sheep (87%), cattle (10%), goats (2.8%), and horses (0.2%) (SSB data 1990 - 2018). On average, the density of domestic grazing animals in Norwegian pastures is 14.5 animals km<sup>2</sup>, which is below the animal density that would induce a SOC loss (<https://kilden.nibio.no>).

| Table 6.28 Distribution of domestic grazing animals <sup>†</sup> density in Norwegian pastures (2018). |                     |
|--------------------------------------------------------------------------------------------------------|---------------------|
| Density (head/km <sup>2</sup> )                                                                        | Grassland areas (%) |
| 0-25                                                                                                   | 84.0                |
| 26-50                                                                                                  | 13.7                |
| 51-75                                                                                                  | 1.7                 |
| >75                                                                                                    | 0.6                 |

<sup>†</sup>: Sheep, cattle, goat, horse. Source: <https://kilden.nibio.no>

Most of the grassland area in Norway exhibits sustainable animal stocking rates, as evidenced by the distribution of domestic animal density by area (Table 6.28). In the rare case of soil degradation, it would be restricted to the closed pasture area designed to maintain a higher density of animals. However, it will not likely occur in the open pastures in extensive grasslands. Considering reindeer would not change this conclusion as both wild and domestic stocking rates remain extremely low, ranging from 0.87 to 2.2 animal km<sup>2</sup> (Reimers 1986; Tveraa et al. 2007). In both cases, severe land degradation responsible for a 30% loss of soil organic carbon is unlikely to occur in Norway in the light of the available stocking rate data.

Considering all these elements, the carbon stock change factors (SCF) were attributed as follows:

**No-till cultivated grass pastures** (*overflatedyrka eng*): Most cultivated grasslands are fertilized annually but are seldom reseeded, except in cases of severe frost damage. Therefore, it is reasonable to assume that most No-till cultivated grass pastures receive only one improvement, qualifying them as improved grassland ( $F_{MG} = 1.14$ ) with medium organic matter input ( $F_I = 1$ ).

**Closed pastures** (*innmarksbeite*): As this grassland type is fertilized annually, it may qualify for an improved grassland ( $F_{MG} = 1.14$ ); however, this grassland may also be the most susceptible to moderate degradation due to higher animal stocking rates ( $F_{MG} = 0.95$ ). Because these two management categories correspond respectively to a loss and a gain of soil organic carbon, we decided to qualify the closed pastures as nominally managed (non-degraded) grassland ( $F_{MG} = 1$ ) with medium organic matter input ( $F_I = 1$ ).

**Other wooded land with crown cover 5-10%** (*annet tresatt areal*): Like for open pastures, other wooded land was considered nominally managed (non-degraded) grassland ( $F_{MG} = 1$ ) with medium organic matter input ( $F_I = 1$ ).

**Open areas (Other non-wooded areas and coastal heath) (*åpne arealer*):** These ecosystems are not cultivated and do not receive any improvements. Moderately degraded grassland may occur very locally, but because of the rather low animal stocking rate and the possibility for the animals to move freely to the less degraded areas, we considered that the open pastures were nominally managed (non-degraded) grassland ( $F_{MG} = 1$ ) with medium organic matter input ( $F_I = 1$ ).

#### Soil Carbon Reference values

For extensive grasslands remaining extensive grasslands, all SCF's are equal to 1; thus, no carbon stock change will occur, and  $SOC_{REF}$  values are not required.

For intensive grasslands, to assign the  $SOC_{REF}$ , an analysis was made of the national soil classification (World Reference Base, WRB, soil taxonomy) database developed by the Norwegian Institute of Bioeconomy Research. The percentage of the total intensive grassland area sampled until now varies between the eight strata defined. The analysis results showed that high-activity clay (HAC) soils predominate in all climate zones, but spodic soils comprise almost one-third of the area in region 2 (Figure 6-19).

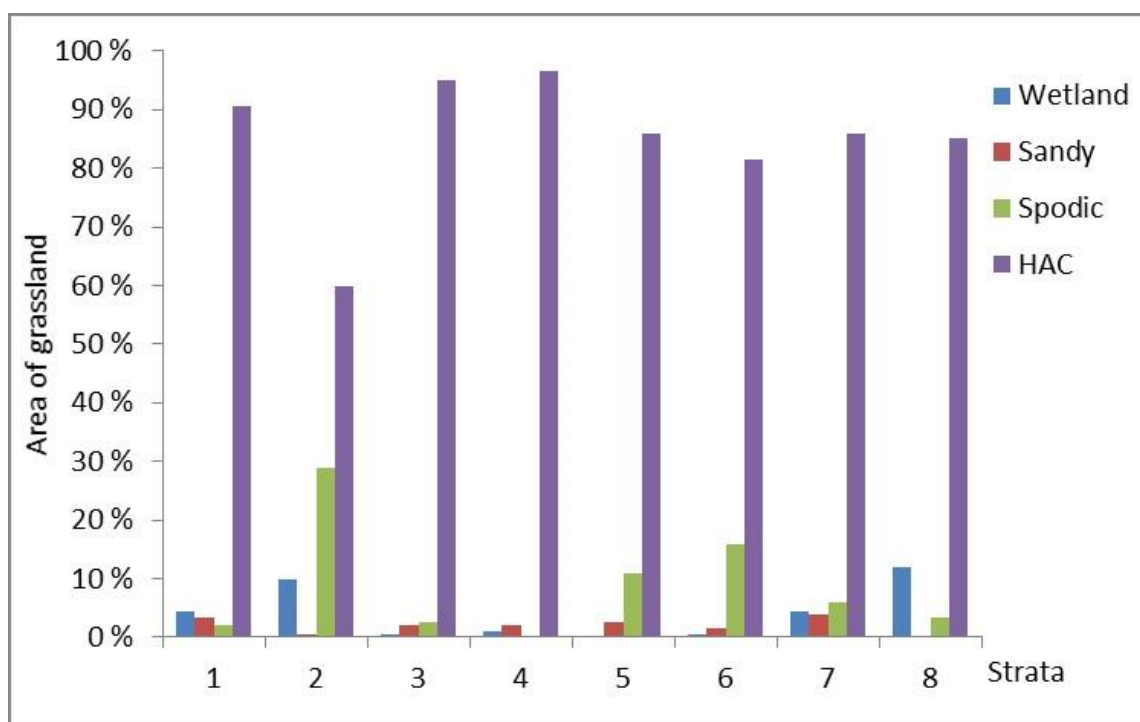


Figure 6-19 Distribution of soil types in intensive grassland areas for the eight strata. The IPCC soil types are high-activity clay soils (HAC): leptosols, fluvisol, phaeosem, albeluvisol, luvisol, umbrisol, cambisol, regosol; wetland soils: gleysols; sandy soils: arenosols; and spodic soils: podzol.

The soil C reference stock ( $\text{SOC}_{\text{REF}}$ ) for the cold temperate moist climate zone in 0-30 cm depth are  $95 \text{ t C ha}^{-1}$ ,  $71 \text{ t C ha}^{-1}$ ,  $115 \text{ t C ha}^{-1}$ , and  $87 \text{ t C ha}^{-1}$  for HAC, sandy, spodic, and wetland soils, respectively; see IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.3. Soil C stock changes were first calculated per stratum and soil type. The final stock changes were given by multiplying the C stocks per stratum and soil type with the fractions for each soil type.

#### 6.6.1.1.3 Organic soils (key category)

Organic soil on intensive grassland remaining intensive grassland is identified as a key category for Level assessment of 1990 according to Approach 2 key category analysis (see Table 6.6).

Organic soils are only found on a fraction of the intensive grasslands, not extensive grasslands.

#### Choice of method

We used the Tier 1 method described for organic soils in cropland remaining cropland (section 6.5.1).

#### Activity data

The area of organic soil on intensive grassland remaining intensive grassland was derived in the procedure described in section 6.3.3.

#### Emission factor

The default EF for shallow-drained, nutrient-rich grassland of  $3.6 \text{ t C ha}^{-1} \text{ yr}^{-1}$  was applied (IPCC 2014b). The choice of EF was based on inspection of orthophotos where it was observed that most of the plots were either with too many trees to allow proper cultivation and thus overgrown drains or on fairly thin soil layers (visible bedrock in some places) such as surface cultivated grasslands. We found the shallow drainage factor to be more appropriate.

#### **6.6.1.2 Uncertainties and time-series consistency**

The uncertainties were estimated for all sink/source categories under the grassland remaining grassland and included in the key category analysis.

For living biomass, the uncertainty estimate of the C stock change and the area were based on the sample variance and estimated as described in section 6.1.3 and is shown in Table 6.3

For the mineral soil pool, a Tier 1 uncertainty assessment was made considering the uncertainty related to the C stock estimate (the stock change factors) using default values and the activity data using the sample variance. Firstly, we estimated the uncertainty of the SOC stock estimate ( $U_C$ ) by propagating the uncertainty of the stock change factors and SOC reference stock. The errors of the stock change factors are provided in IPCC 2006, Vol. 4, Ch. 6, Table 6.2. For the improved grassland management stock change factor, the uncertainty is  $\pm 11\%$ . The stock change factor for nominally managed grassland has no associated uncertainty as it is the reference condition. The default C reference stock has an uncertainty of  $\pm 90\%$ , according to IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.3. Secondly, the uncertainty of the activity data was combined with that of the C stock change per hectare. The uncertainty in the activity data ( $U_A$ ) covers both uncertainty in the estimates of the grassland management type (SSB data) and uncertainty in the areas of grassland remaining grassland determined in the NFI. The first source of uncertainty, which is related to the estimation of the grassland management system, was estimated to be close to zero by SSB. According to the sample validations routinely performed by the collection agency (NAA), farmers are unlikely to make errors (or false reporting), and very few of these errors



exist. The second source of uncertainty in the activity data, i.e., of the area estimate of grassland remaining grassland, was determined by the sample error and equal to 13% (Table 6.4). Although the area included organic soils, we assume the uncertainty for the mineral soil area is similar. Uncertainties of the area estimates are quantified as described in section 6.1.3. The total uncertainty for the mineral soil estimate was propagated using Equation 3.1 of 2006 IPCC Guidelines, vol.1, ch. 3, and was equal to 92%.

The uncertainty for organic soils is based on default values for the emission factor and the sample error for the area estimate. Uncertainty estimates for both mineral and organic soils are shown in Table 6.4.

#### **6.6.1.3 QA/QC and verification**

The Tier 1 QC procedures for living biomass, mineral soil, and organic soil emission estimates were performed. The Tier 1 method used for mineral soils on intensive grasslands was elicited for external QA before the 2013 submission.

#### **6.6.1.4 Recalculations**

Tree living biomass estimates were updated for the whole time series due to updated area estimates and updated national emission factors for gains and losses.

Similarly, mineral soil emissions were updated for the whole time series due to updated mineral area estimates in the database. Additionally, rounding to 2 decimal places for the distribution of climate zone areas per soil type significantly impacts the emissions. In the current submission, the suppression of the rounding is responsible for the changes observed between the previous and current submissions.

See chapter 10.2.4 for details.

#### **6.6.1.5 Planned improvements**

Living biomass, mineral soils, and organic soils

No planned improvements.

### **6.6.2 Land converted to grassland, 4C2**

Emissions from land converted to grassland were primarily caused by net C losses in the DOM pool on forest land converted to grassland. There were land-use conversions from forest land, wetlands, and settlements to grassland. For forest land converted to grassland, C emissions were estimated from changes in living biomass, DOM, and mineral soil. All the area of wetlands converted to grassland was on organic soils. Emissions were therefore estimated for stock changes in living biomass and organic soils for this land use conversion. All the area of settlements converted to grassland was on mineral soils.

Forest land converted to intensive grasslands is identified as a key category concerning living biomass and DOM in the Level assessment 1990 and/or 2021 and/or Trend assessment 1990 - 2021 (see Table 6.6).

#### **6.6.2.1 Methodological issues**

##### **6.6.2.1.1 Living biomass (key category)**

The sink/source category living biomass on land converted from forest land to intensive grasslands is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

The choice of method, activity data, and assumptions related to estimating C stock changes in tree living biomass on land converted to grassland are identical to those described under forest land (section 6.4).

All lands to grassland results in instant grass biomass gains of 3.995 tC ha<sup>-1</sup> for boreal climate, 3.055 tC ha<sup>-1</sup> for cool temperate dry climate, and 6.392 tC ha<sup>-1</sup> for cool temperate moist climate in the first year of conversion in accordance with default Tier 1 methodology in the IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4, with non-woody carbon factor of 0.47 tC (t d.m.)<sup>-1</sup>.

##### Assumptions/justification

See IPCC 2019 refinement justification for annual crop biomass losses under section 6.5.2.

##### **6.6.2.1.2 Dead organic matter (key category)**

The sink/source category dead organic matter on land converted from forest land to intensive grasslands is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

##### Method choice, C stock change factors, and activity data

DOM for forest land to grassland applies a similar Tier 1 methodology as for lands to forest land (section 6.4.2). The difference is that instead of DOM gains, there are DOM losses. Furthermore, the losses occur instantly within the first year of conversion instead of being distributed over 20 years. Table 6.29 presents the DOM carbon stock loss factors for forest land converted to grassland currently found in Norway.

| <b>Table 6.29 Instant DOM carbon stock loss factor (t C ha<sup>-1</sup>) for forest land converted to grassland</b> |                                    |                 |                                       |                 |
|---------------------------------------------------------------------------------------------------------------------|------------------------------------|-----------------|---------------------------------------|-----------------|
| <b>Ecological climate zones</b>                                                                                     | <b>Litter (tC ha<sup>-1</sup>)</b> |                 | <b>Dead wood (tC ha<sup>-1</sup>)</b> |                 |
|                                                                                                                     | <b>deciduous</b>                   | <b>conifers</b> | <b>deciduous</b>                      | <b>conifers</b> |
| Cool Temperate Moist Mountain System                                                                                | 6                                  | 8               | 21.2                                  | 48.1            |
| Cool Temperate Dry Steppe                                                                                           | 40                                 | 31              | 26.2                                  | 8               |
| Cool Temperate Oceanic Forest                                                                                       | 6                                  | 7               | 36.8                                  | 36.8            |
| Cool Temperate Continental Forest                                                                                   | 27                                 | 70              | 23.6                                  | 22.1            |

For wetlands converted to grassland and settlements converted to grassland, we apply the Tier 1 method that assumes no net change in the C pool of dead organic matter, thus, the notation key NO is used in the CRF-tables.

#### 6.6.2.1.3 Mineral soils

A Tier 1 method is used to estimate C stock changes on land converted to grassland.

#### Choice of method, C stock change factors, and activity data

The same Tier 1 methodology applied for lands converted to forest land is also applied here (see section 6.4.2). The national mean mineral soil CSC rate for lands to grassland for 1990 – 2021 can be found in Table 6.30.

| <b>Table 6.30 Annual mineral soil carbon stock change rates (mean ± standard deviation in t C ha<sup>-1</sup> yr<sup>-1</sup>) for lands converted to grassland (1990 – 2021).</b> |                             |                    |                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|--------------------|--------------------|
| <b>Grassland subcategory</b>                                                                                                                                                       | <b>IPCC climate region</b>  | <b>Forest land</b> | <b>Settlements</b> |
| Intensive                                                                                                                                                                          | <b>Cool Temperate Dry</b>   | 0.02               |                    |
|                                                                                                                                                                                    | <b>Cool Temperate Moist</b> | 0.0765 ± 0.0065    | 0.6 ± 0.41         |
| Extensive                                                                                                                                                                          | <b>Cool Temperate Moist</b> |                    | 0.679              |

#### 6.6.2.1.4 Organic soils

Emissions from organic soils on land converted to grassland were estimated using the Tier 1 method. Only wetlands on organic soils have been converted to grassland, and these areas were assumed drained to enable grassland production.

#### Method choice, emissions factors, and activity data

The Tier 1 method was used, applying a default emissions factor of  $3.6 \text{ t C ha}^{-1} \text{ yr}^{-1}$  for shallow-drained grasslands in the temperate zone from the IPCC 2013 Wetlands supplement. The NFI database was used to estimate the areas of wetlands converted to grassland on organic soils.

#### **6.6.2.2 *Uncertainties and time-series consistency***

The total uncertainties for living biomass, DOM, mineral, and organic soils are shown in Table 6.3 and Table 6.4. All methods were applied consistently for the entire time-series.

#### **6.6.2.3 *QA/QC and verification***

The standard Tier 1 QC procedures were performed during the estimation of C stock changes for land converted to grassland.

#### **6.6.2.4 *Recalculations***

Living biomass, dead organic matter, and mineral soil estimates were updated partly due to reclassifying the land-use class of a few plots in the database and extrapolation. Most of the recalculation comes from forest land to grassland.

Cropland to grassland is a new land-use conversion and has resulted in emissions from drained organic soil from 2012 to the current reporting year.

See chapter 10.2.4 for details.

#### **6.6.2.5 *Planned improvements***

Living biomass, dead organic matter, mineral soils, and organic soils

No planned improvements.

### **6.6.3 *Completeness***

The reporting of emissions from grassland is complete.

## **6.7 Wetlands – 4D**

Wetlands in Norway cover almost 12% of the total land area. Most of the wetlands in Norway are unmanaged mires, bogs and fens, lakes, and rivers. C stock changes (CSC) in tree living biomass are reported for both managed and unmanaged wetlands. Managed wetlands are peat extraction areas and mires with ditches. Reservoirs (dams) are, by definition, managed; however, Norway has not established a methodology for estimating emissions. Hence all flooded lands remaining flooded lands are reported as NE, and their areas are reported under unmanaged wetlands. For peat extraction sites, both on-site and off-site emissions are reported. On lands converted to wetlands, emissions and removals are reported for living biomass, DOM, and soils.

### 6.7.1 Wetlands remaining wetlands, 4D1

The NFI contains data on CSC in living biomass (trees) on wooded mires, for which the associated emissions and removals have been reported. C stock changes in DOM are not estimated for managed or unmanaged wetlands. Emissions from drained organic soil for peat extraction and other managed wetlands are estimated according to the IPCC 2006 Guidelines and IPCC 2013 Wetlands supplement. Organic soils in unmanaged wetlands not subject to drainage were assumed to be in equilibrium. No methods are available for estimating the C emissions or removals in these areas.

#### 6.7.1.1 Methodological issues

##### 6.7.1.1.1 Living biomass

We report tree living biomass on both managed and unmanaged wetlands. To estimate CSC in living biomass, we applied the Tier 3 method (section 6.4.1).

##### 6.7.1.1.2 Dead organic matter and mineral soil

CSC in DOM and mineral are reported as NO.

##### 6.7.1.1.3 Peat extraction (managed wetlands) – Organic soil (key category)

The source category peat extraction on organic soil is identified as a key category for Level assessment 1990 and Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).

For wetlands subject to peat extraction, we use a Tier 1 method for on-site emissions and a Tier 2 method for off-site emissions. Under the default method, the activity data do not distinguish between peatlands under peat extraction and those being converted for peat extraction (IPCC 2006; IPCC 2014b). Therefore, the area of land converted to peat extraction is reported as NE (see below for estimation of non-significant sources). The emissions from removing trees during clearing are included under living biomass and reported as IE. Other changes in C stocks in living biomass on managed peatlands are assumed to be zero (IPCC 2006).

The area utilized for peat extraction is estimated to be 2 kha for the time series 1990 - 2021. On-site emissions caused by peat extraction are thus constant over the inventory period. Soil C stock changes are estimated to be  $-5.6 \text{ kt C yr}^{-1}$ , which is equal to emissions of  $20.5 \text{ kt CO}_2 \text{ yr}^{-1}$ . On-site emissions of  $\text{N}_2\text{O}$  and  $\text{CH}_4$  are estimated to be  $0.0009 \text{ kt N}_2\text{O yr}^{-1}$  and  $0.0658 \text{ kt CH}_4 \text{ yr}^{-1}$ , respectively. Off-site emissions vary over the years. The off-site emissions in 2021 were  $45.2 \text{ kt CO}_2$ . Total emissions from peat extraction, including on-site emissions, represent  $67.9 \text{ kt CO}_2$  equivalents in 2021.

### Choice of method, activity data, and emission factor

For wetlands subject to peat extraction, on-site emissions are estimated with default emission factors from the IPCC 2013 Wetlands supplement (boreal / temperate zone) and are hence considered a Tier 1 method. Off-site CO<sub>2</sub> emissions are estimated using a national emission factor of 0.05 t C / m<sup>3</sup> based on expert judgement, and it is a Tier 2 method. We assume a peat dry matter density of 0.1 t m<sup>-3</sup> and a C content of 50%.

**Table 6.31 Emission factors used to estimate on- and off-site emissions from peat extraction and their estimated uncertainties.**

| Gas                   | Emission factor (EF)                                         | EF uncertainty (% 2 SE) | Activity data uncertainty% | Total uncertainty% |
|-----------------------|--------------------------------------------------------------|-------------------------|----------------------------|--------------------|
| <b>On-site</b>        |                                                              |                         |                            |                    |
| CO <sub>2</sub>       | 2.8 t CO <sub>2</sub> C ha <sup>-1</sup> yr <sup>-1</sup>    | 50                      | 100                        | 110                |
| CH <sub>4</sub> LAND  | 6.1 kg CH <sub>4</sub> ha <sup>-1</sup> yr <sup>-1</sup>     | 80                      | 100                        | 128                |
| CH <sub>4</sub> DITCH | 542 kg CH <sub>4</sub> ha <sup>-1</sup> yr <sup>-1</sup>     | 81                      | 100                        | 129                |
| Frac <sub>ditch</sub> | 0.05                                                         |                         |                            |                    |
| N <sub>2</sub> O      | 0.30 kg N <sub>2</sub> O-N ha <sup>-1</sup> yr <sup>-1</sup> | 113                     | 100                        | 151                |
| <b>Off-site</b>       |                                                              |                         |                            |                    |
| CO <sub>2</sub>       | 0.05 t C m <sup>-3</sup> air-dry peat                        | 50                      | 50                         | 71                 |

A survey was done among Norwegian peat producers to provide information on current and previous peat extraction production areas. In addition, a supplemental digital orthophoto study of identified ditched marsh areas where peat extraction was likely to have occurred was done. Off-site emissions from extracted peat volume were based partly on data from the Norwegian Food Safety Authority (1990 - 2007) and partly on information from a peat producer survey conducted in 2015 (covering the years 2008 - 2014) and in 2021 (covering the years 2015-2021). The data series are incomplete for all years (1994-1997 have data gaps), and interpolation has been done to ensure a consistent time-series. The peat extraction activity data is detailed in Søgård (2017).

#### 6.7.1.1.4 Mires with ditches (managed wetlands) – Organic soil (key category)

The source category mires with ditches on organic soil is identified as a key category for Level assessment 1990 and Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).

Mires with ditches where no land-use change has occurred. This could be, e.g., the result of drainage to achieve land-use change (whether successful or not) or mires where ditches occur for other purposes.

#### Choice of method, activity data, and emission factor

Due to the lack of national emissions factors, a Tier 1 method was chosen.

Activity data were available from the same NFI registrations as described for Forest land remaining Forest land (drained organic soils) (chap.6.4.1 ). Drainage was historically carried out primarily to facilitate forest establishment or other land use changes. Many ditches in wetlands were established to drain surrounding areas (in other land uses). Further, we assume many results from “unsuccessful” afforestation/land use changes in the past. All drained organic soil is found in the temperate cool climate zone. Only the climate zone determines the default emission factor for CO<sub>2</sub> emissions according to the IPCC 2013 Wetlands supplement.

We used the default emission factor for temperate cool climate from the IPCC 2013 Wetlands supplement, 2.6 t C-CO<sub>2</sub> yr<sup>-1</sup> ha<sup>-1</sup>, as it represents the most up-to-date information.

#### 6.7.1.1.5 Unmanaged wetlands – Organic soil

Organic soils in unmanaged wetlands not subject to drainage were assumed to be in equilibrium and reported with notation key NO. No methods are available for estimating the C emissions or removals in these areas.

#### **6.7.1.2 Uncertainties and time-series consistency**

The estimation of the uncertainty of the area and the C stock of tree living biomass is described in section 6.3.7.

For peat extraction, on- and off-site CO<sub>2</sub> emission uncertainties were combined by the weighted sum of the variances (square of total uncertainty% in Table 6.31), assuming no (0) correlation between on- and off-site emissions. The assumption of no correlation is based on the fact that on-site emissions will occur for many years even if no peat extraction would be conducted and off-site emissions would be 0. The weights (w) were given by squared proportions of the total emissions ( $w = (40/53)^2 = 0.57$  for off-site emissions and  $w = (13/53)^2 = 0.06$  for on-site emissions). Also, the uncertainties for CH<sub>4</sub> on land between and in ditches were combined for the KCA. It was the weighted average of the variance of the emission factors for land between ditch and their covariance, assuming a direct correlation of 1. The correlation of 1 was chosen because of the increase in one area due to an increase in the other, and vice versa. The weight was given by the squared ditch proportion. In sum, the uncertainty is assumed to be 110% for CO<sub>2</sub>, 128% for CH<sub>4</sub>, and

151% for N<sub>2</sub>O emissions. Uncertainties for CO<sub>2</sub> emissions estimated from drained organic soils on wetlands used for peat extraction are shown in Table 6.4 and for CH<sub>4</sub> and N<sub>2</sub>O in Table 6.5.

For mires with ditches (managed wetlands), uncertainties of the EF use the IPCC default uncertainty.

#### **6.7.1.3 QA/QC and verification**

The standard Tier 1 QA/QC procedures were performed. In addition, QA by a national expert was performed for the peat extraction off-site CO<sub>2</sub> emission factor (Søgaard 2017).

#### **6.7.1.4 Recalculations**

Recalculation of living biomass and drained organic soil is due to changes in the activity data and updated extrapolation for other wetlands remaining other wetlands.

See chapter 10.2.4 for details.

#### **6.7.1.5 Planned improvements**

Living biomass, dead organic matter, mineral soils, peat extraction, mires with ditches and unmanaged wetlands

No planned improvements.

### **6.7.2 Land converted to wetlands, 4D2**

Conversion of land to wetlands is most likely a slow process unless in the form of land flooding, which enables rapid inundation. Only a few small-scale hydropower dams have been created in streams in the last 20-30 years, and the total area is less than 4 kha. We consider emissions from this conversion category negligible and report them using the notation key NO. We report C stock changes in living biomass, DOM, and soils for forest land converted to other wetlands. The area of land converted to peat extraction and soil-related emissions are reported as NE because it is considered negligible (see below, non-significant sources).

#### **6.7.2.1 Methodological issues**

Emissions from land converted to wetlands were estimated for living biomass, DOM, mineral and organic soils.

##### **6.7.2.1.1 Living biomass (key category)**

The source category living biomass on land converted from forest land to managed wetlands is identified as a key category for Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).



C stock changes in the tree living biomass pool were estimated using the Tier 3 approach (section 6.4.1), where gains and losses are recorded in the NFI.

Conversions from grassland to wetlands results in instant grass biomass losses of 3.995 tC ha<sup>-1</sup> for boreal climate; 3.055 tC ha<sup>-1</sup> for cool temperate dry climate; and 6.392 tC ha<sup>-1</sup> for cool temperate moist climate in the first year of conversion in accordance with default Tier 1 methodology in IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4, with non-woody carbon factor of 0.47 tC (t d.m.)<sup>-1</sup>).

#### 6.7.2.1.2 Dead organic matter (key category)

The source category dead organic matter on land converted from forest land to managed wetlands is identified as a key category for Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).

DOM for forest land to wetlands applies a similar Tier 1 methodology as for lands to forest land (section 6.4.2). The difference is that instead of DOM gains, there are DOM losses. Furthermore, the losses occur instantly within the first year of conversion instead of being spread over 20 years. Table 6.32 presents the DOM carbon stock loss factors for forest land converted to wetlands in Norway.

**Table 6.32 Instant DOM carbon stock loss (t C ha<sup>-1</sup>) for forest land converted to wetlands.**

| Ecological climate zones          | Litter (tC ha <sup>-1</sup> ) |          | Litter (tC ha <sup>-1</sup> ) |          |
|-----------------------------------|-------------------------------|----------|-------------------------------|----------|
|                                   | deciduous                     | conifers | deciduous                     | conifers |
| Cool Temperate Continental Forest | 27                            | 70       | 23.6                          | 22.1     |

#### 6.7.2.1.3 Mineral soil

The same Tier 1 methodology as applied for lands to forest land is also applied here (see section 6.4.2). Conversions to wetlands occur only from forest land and extensive grasslands. Moreover, no CSC occurs for these transitions on mineral soil.

#### 6.7.2.1.4 Organic soil

For drained organic soils, we used the default emission factor for temperate cool climate on forest land, which is 2.6 t C ha<sup>-1</sup> yr<sup>-1</sup> (IPCC 2014b). The conversion of extensive grasslands to wetlands on organic soil cannot occur, and the notation key NO is therefore reported in the CRF.

#### **6.7.2.2 QA/QC and verification**

The standard Tier 1 QA/QC procedures were performed.

#### **6.7.2.3 Recalculations**

The recalculations for all estimates were due to updated extrapolation for the last four common years.

See chapter 10.2.4 for details.

#### **6.7.2.4 Planned improvements**

Living biomass, dead organic matter, mineral soils, and organic soils

No planned improvements.

### **6.7.3 Completeness**

The reporting for emissions and removals occurring on wetlands is complete.

CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from lands converted to peat extraction are reported as NE. An assessment was made of the likely level of emissions from lands converted to peat extraction. For the aggregate criteria concerning all emissions reported as NE (threshold: a relative 0.1% of non-LULUCF national emissions), see section 6.1.5. For the criteria concerning only the likely emissions from lands converted to peatland extraction (must be < 0.05% of non-LULUCF national emissions; must be < 500 kt CO<sub>2</sub> eq yr<sup>-1</sup>), see below.

Norway reports emissions for Lands Remaining Peatland Extraction but not for Lands converted to Peatland Extraction. The area estimated to be subject to conversion to Peatland Extraction was based on producer surveys and expert judgement to be 0.447 kha; on and off-site emissions were estimated from the assumption 1) extracted volumes are evenly distributed across all Peatland Extraction areas and 2) extraction only begins 10 years after conversion.

The likely level of emissions of CO<sub>2</sub> is 9.1 kt yr<sup>-1</sup> (range 7.4 - 11.3 kt yr<sup>-1</sup>). For CH<sub>4</sub>, the likely emissions are 0.4 kt CO<sub>2</sub> eq yr<sup>-1</sup>, and for N<sub>2</sub>O, it is 0.1 kt CO<sub>2</sub> eq yr<sup>-1</sup>.

### Box 3 - Peat extraction

To gather information about peat extraction, two surveys have been conducted. One in 2015 and one in 2021. In the survey of 2015, the producers were asked to list the peatlands they used, with information about when they started using them, the area and if relevant when they stopped using them. In the survey of 2021, the producers were asked whether they had started using a new area of peatland since 2015. Only one producer answered yes to this and was asked directly how large the area was. Based on the results from these two surveys, the total area of peatland drained for peat extraction since 1990 was calculated to be 694 ha. Assuming an even conversion over the years, and a conversion time of 20 years, the average area being converted at any given moment has been calculated like this:  $\text{Lands converted for peat extraction (ha)} = \text{total area (694 ha)} / \text{number of years (31 years)} * 20 \text{ years} = 447.7 \text{ ha}$

The peat extracted from lands converted for peat extraction was also calculated. It was assumed that it takes about 10 years from the initial conversion, until the first peat extraction and it was assumed that there is an even distribution of peat extraction on the areas used for peat extraction (estimated to be 2000 ha). Based on this the average peat extraction (m<sup>3</sup>/ha) was calculated for each year. Then the peat extracted from land converted for peat extraction was calculated for each year:  $\text{Peat extracted on land converted for peat extraction} = \text{Peat (m}^3\text{)/ha} * \text{Lands converted for peat extraction (447.7 ha)} / 20 * 10$

The numbers were then used to calculate the off-site and on-site emissions of land converted for peat extraction, using the same methods as for lands remaining peat extraction.

To evaluate if these emissions qualify as “non-significant”, they were related to the Norwegian emissions from all sectors except the LULUCF sector, as given in chapter 1.7 of this document and section 0. For each of the three gasses, the likely emissions were less than the relative threshold of 0.05% of national non-LULUCF emissions and are lower than the absolute threshold of 500 kt CO<sub>2</sub> eq yr<sup>-1</sup>. Based on this (and the aggregate criterion, section 6.1.5), we conclude that emissions from Lands converted to Peatland Extraction can be considered non-significant.

## 6.8 Settlements – 4E

Settlements cover a little more than 2% of the area of Norway. Settlements is a diverse land-use class consisting of, for example, residential areas, roads, recreation areas, powerlines within forests, gravel pits, mines, and industrial areas. The land-use class is especially important for the sub-group of land converted to settlements because of increased land-use conversions since 1990.

All settlement areas are classified into subdivision classes according to their surface properties (using NFI variables “area description”, “area type”, and “area use”). However, the application of sub-categories to estimate emissions is used differently for settlements remaining settlements and land converted to settlements (see sections 6.8.1 and 6.8.2).

For each NFI plot categorized as a Settlement, we know the proportion of greenspace area (the proportion of land area covered by vegetation or open soil). It is defined in 10% classes in the NFI and converted to a proportion of each plot, which is greenspace for the Tier 1 method (Table 6.33).

The area within the settlements defined as infrastructure or paved over is estimated as the non-greenspace proportion of the total area by default. Currently, the NFI does not discriminate between the non-greenspace proportion area, which are man-made constructions, and naturally present bare rocks. The current assumption is to treat all non-greenspace on settlement plots as man-made constructions, thereby classifying the area as either paved or infrastructure.

**Table 6.33 Percent total greenspace. That is the proportion of land area covered by vegetation or open soil used for the Tier 1 methodology**

| <b>NFI range in% total greenspace</b> | <b>Total greenspace% as applied for the calculations in the GHG inventory (Tier1)</b> |
|---------------------------------------|---------------------------------------------------------------------------------------|
| 0 – 10%                               | 0%                                                                                    |
| 11 – 20%                              | 15%                                                                                   |
| 21 – 30%                              | 25%                                                                                   |
| 31 – 40%                              | 35%                                                                                   |
| 41 – 50%                              | 45%                                                                                   |
| 51 – 60%                              | 55%                                                                                   |
| 61 – 70%                              | 65%                                                                                   |
| 71 – 80%                              | 75%                                                                                   |
| 81 – 90%                              | 85%                                                                                   |

The IPCC 2006 Guidelines do not define clear subdivisions of the Settlements category. This inconsistency is underlined in the IPCC 2019 Refinement. In the IPCC 2006 Guidelines, Vol. 4, Ch. 8, it is stated that *"Settlement management classes could include turf grass (e.g., lawns and golf courses), urban woodlands, gardens, refuse areas (e.g., garbage dumps), barren areas (exposed soil), and infrastructure (e.g., roadways, houses, and buildings)"*. Further, regarding the choice of Tier 1 stock change factors for mineral soil, the IPCC 2006 Guidelines define four settlement subdivisions for lands converted to settlements defined as the portion of settlement area that is paved over, turfgrass, cultivated, and wooded (IPCC 2006 Guidelines, Vol. 4, Ch. 8, section 8.3.3.2). This has been used as a base for defining subdivision classes of settlements for Norway which reflect national conditions.

Based on knowledge of land usage from the NFI, we can subdivide Settlements into four classes to reflect the degree of impact that settlement land use and management has on soil C stocks: (1) Infrastructure, (2) Paved over, (3) Turfgrass, and (4) Vegetated (Table 6.34). Turfgrass and Vegetated on mineral soil wooded areas were classified into a fifth category, "wooded" (5).

| <b>Table 6.34 Settlements subdivision classes</b> |                                                                                                                                                                                                                      |
|---------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Classes</b>                                    | <b>Definition</b>                                                                                                                                                                                                    |
| Infrastructure (I)                                | Soil is totally removed in most cases (e.g. motorways, houses, and other buildings). <sup>1</sup>                                                                                                                    |
| Paved (P)                                         | Soil is paved over (e.g. forest roads, sidewalks) <sup>1</sup>                                                                                                                                                       |
| Turfgrass (T)                                     | Receives cutting and removal of vegetation and at least one improvement such as fertilization, species improvement, and irrigation (e.g. golf courses, gardens, parks).                                              |
| Vegetated (V)                                     | Receives periodic cutting and removal of above-ground vegetation without significant management improvements (e.g. power lines, road edge zones).                                                                    |
| Wooded (W)                                        | The presence of trees is used to partition the greenspace area (T and V) into wooded areas and non-wooded areas. If at least one tree is present, the greenspace (T or V) is defined as wooded when on mineral soil. |

<sup>1</sup> Bare rock (soil removed or bare rock before transition) may or may not be included in the category; the currently used data does not record it.

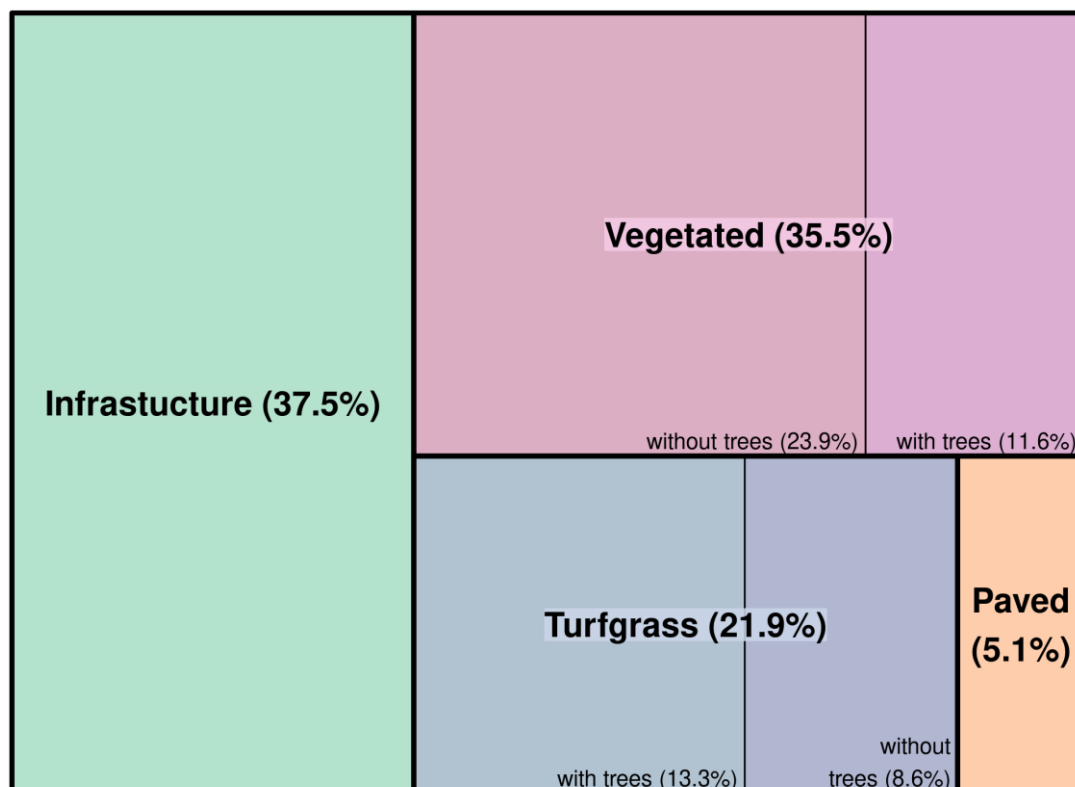


Figure 6-20 Settlement subcategory area distribution (2017-2021)

### 6.8.1 Settlements remaining settlements, 4E1

On settlements remaining settlements, we report C stock changes (CSC) in living biomass, DOM, mineral and organic soils using Tier 1 methods. Organic soils on settlements remaining settlements is a key category in the 2021 level assessments and 1990 - 2021 trend assessment.

#### 6.8.1.1 Methodological issues

##### 6.8.1.1.1 Living biomass

To estimate CSC in the living biomass pool, a Tier 1 method is used, assuming no stock change and NO is reported. This is because trees are not measured in settlements in the NFI due to the relatively small amounts of living biomass in settlements (Løken et al. 2012). In a specific study, trees were measured in land-use classes where trees are usually not measured in the NFI, including those within settlements (Løken et al. 2012). A panel of NFI plots visited in 2009 containing almost 900 plots within settlements was used in the study.

Settlements cover slightly more than 2% of the Norwegian land area but contain only approximately 0.4% of the total biomass stock (Løken et al. 2012).

#### 6.8.1.1.2 DOM and mineral soils

C stock changes in DOM and mineral soil pools are also estimated using a Tier 1 method. This implies an assumption that no CSC occurs, and hence the notation key NO is used.

#### 6.8.1.1.3 Organic soils (key category)

The source category organic soil is identified as a key category for Level assessment 2021 and Trend assessment 1990-2021 according to Approach 2 key category analysis (see Table 6.6).

Norway utilizes the Tier 1 methodology (IPCC 2006; IPCC 2014b) to estimate CO<sub>2</sub> emissions from settlements remaining settlements on drained organic soils. The Tier 1 method utilizes Equation 2.26  $L_{\text{Organic}} = \sum (A \cdot EF)_c$ , where  $L_{\text{Organic}}$  = annual carbon loss from drained organic soils (tonnes C yr<sup>-1</sup>), A = land area of drained organic soils in climate type c (ha), and EF = emission factor for climate type c (tonnes C ha<sup>-1</sup>yr<sup>-1</sup>) (IPCC 2014b). The differing subdivision classes on settlements necessitate different EFs applied to the area of drained organic soil on settlements.

According to IPCC (2014b), it is “good practice to take the default EF of the land-use category closest to national conditions of drained organic soils under Settlements”. We have allocated IPCC (2014b) default EFs to the different subdivision classes as described in Table 6.35.

**Table 6.35 Settlements subdivision classes and their associated Tier 1 EF's on organic soils. EF for CO<sub>2</sub> (tC ha<sup>-1</sup> yr<sup>-1</sup>) is from Table 2.1 in the IPCC 2013 Wetlands supplement.**

| Classes                       | CO <sub>2</sub> (tC ha <sup>-1</sup> yr <sup>-1</sup> ) | IPCC land use category <sup>1</sup>       |
|-------------------------------|---------------------------------------------------------|-------------------------------------------|
| <i>Temperate climate zone</i> |                                                         |                                           |
| Paved (P)                     | 3.6                                                     | Grassland, shallow-drained, nutrient-rich |
| Turfgrass (T)                 | 6.1                                                     | Grassland, deep-drained, nutrient-rich    |
| Vegetated (V)                 | 3.6                                                     | Grassland, shallow-drained, nutrient-rich |
|                               |                                                         |                                           |
| <i>Boreal climate zone</i>    |                                                         |                                           |
| Paved (P)                     | 5.7                                                     | Grassland, drained                        |
| Turfgrass (T)                 | 5.7                                                     | Grassland, drained                        |
| Vegetated (V)                 | 5.7                                                     | Grassland, drained                        |

1) We do not have information to separate nutrient-rich and nutrient-poor and assume all temperate plots to be nutrient rich. For boreal climate zone, default EFs are not differentiated between deep or shallow drained.

### **6.8.1.2 *Uncertainties and time-series consistency***

Uncertainties for settlements use the Tier 1 uncertainties provided in the IPCC 2013 Wetlands supplement, Table 2.1. Uncertainties are shown in Table 6.3 and estimated as described in section 6.1.3.

### **6.8.1.3 *QA/QC and verification***

The QA/QC plan was performed according to the Tier 1 procedure. External QA was carried out in 2021 for the settlement subdivision methodology.

### **6.8.1.4 *Recalculations***

Recalculations for organic soils were due to database updates and extrapolation.

See chapter 10.2.4 for details.

### **6.8.1.5 *Planned improvements***

Living biomass, dead organic matter, mineral soils and organic soils

No planned improvements.

## **6.8.2 Land converted to settlements, 4E2**

The conversion of land to settlements is a significant source of emissions, primarily due to forest land conversions. Forest land converted to settlements is identified as a key category concerning living biomass, DOM, mineral soil, and organic soil for Level assessment 1990 and 2021 and/or Trend assessment 1990 - 2021(see Table 6.6).



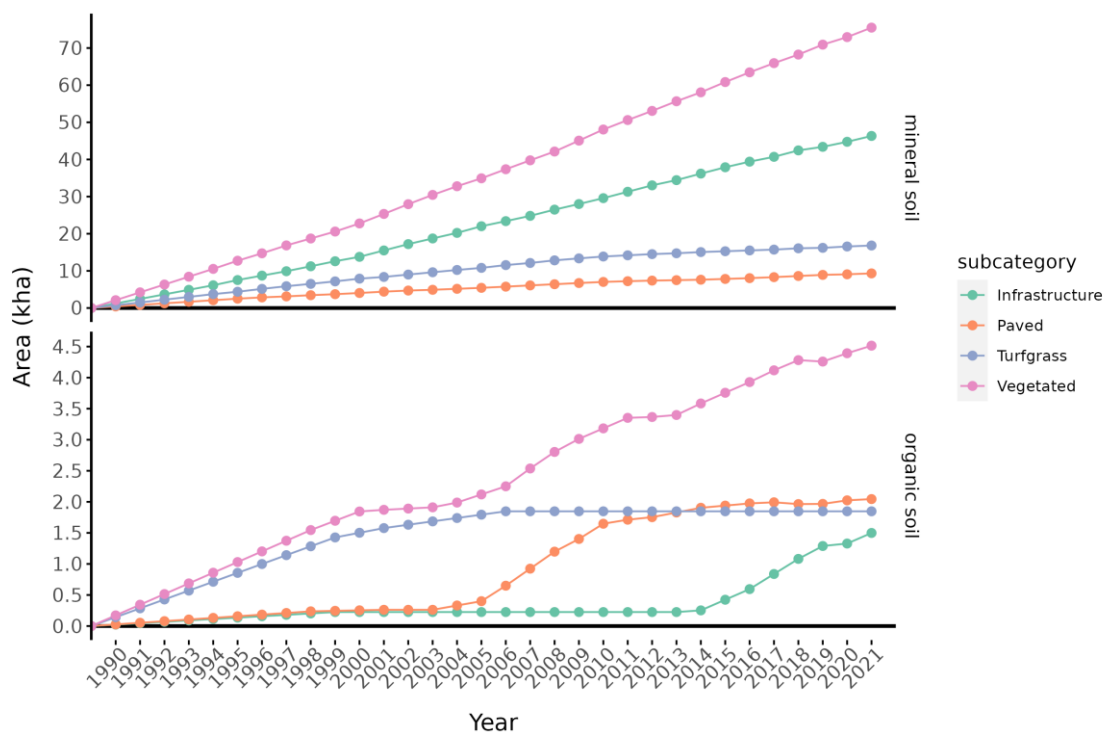


Figure 6-21 Cumulative land-use change area to settlement subcategories (excluding 20-year transition rule to remaining category).

### 6.8.2.1 Methodological issues

#### 6.8.2.1.1 Living biomass (key category)

The source category living biomass on land converted from forest land to settlements is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

#### Woody biomass

For forest land and wetlands<sup>36</sup> converted to settlements, a Tier 3 methodology for tree living biomass based on NFI measurements is used. Tree measurements are usually available before the conversion if the area is tree covered. While trees are not measured on settlements, the NFI records which of the trees remain on the converted sample plot

<sup>36</sup> With at least 5% crown cover. At the latest since 2007, trees are measured independent of crown cover.

the first time the sample plot is visited after the conversion. Diameter and height measurements are, however, not carried out. Based on which trees were removed, the C stock change on the converted sample plots is calculated using the last biomass measurement before conversion, assuming no increment. The C stock of the last measurement minus the C stock of the removed trees is then used as the C stock of the plot assuming no changes in the future. The recording of which trees remain on a converted sample plot started in 2005. In the time-series before 2005, we assume that all trees were removed in the year when the land-use change was observed. An example of a situation where land is converted to settlements with remaining trees is a forested sample plot of which the biggest part of the plot is converted to a house, while some of the trees are still alive inside what is now a garden.

Tree measurements have been available for grassland since 2007, and a Tier 2 method is applied. Sample plots converted from grassland to settlements since 2007 did not have tree living biomass.

No tree biomass losses or gains are reported for conversions from croplands and other lands to settlements.

#### Non-woody biomass

Conversions from grassland to settlements results in instant grass biomass losses of 3.995 tC ha<sup>-1</sup> for boreal climate, 3.055 tC ha<sup>-1</sup> for cool temperate dry climate, and 6.392 tC ha<sup>-1</sup> for cool temperate moist climate in the first year of conversion in accordance with default Tier 1 methodology in IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4, with non-woody carbon factor of 0.47 tC (t d.m.)<sup>-1</sup>.

Conversions from cropland to settlements results in instant annual crop biomass losses of 4.7 tC ha<sup>-1</sup> in the first year of conversion following default Tier 1 methodology in IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9, with non-woody carbon factor of 0.47 tC (t d.m.)<sup>-1</sup>.

#### Assumptions/justification

See IPCC 2019 Refinement justification for annual crop biomass losses under section 6.5.2.

#### 6.8.2.1.2 Dead organic matter (key category)

The source category dead organic matter on land converted from forest land to settlements is identified as a key category for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

DOM for forest land to settlements applies a similar Tier 1 methodology to lands converted to forest land (Section 6.4.2 ). The difference is that instead of DOM gains, there are DOM losses. Furthermore, the losses occur instantly within the first year of conversion instead of being spread over 20 years. Table 6.36 presents the DOM carbon stock loss factors for forest land converted to settlements in Norway.

| <b>Table 6.36 Instant DOM carbon stock loss (t C ha<sup>-1</sup>) for forest land converted to settlements</b> |                                    |                 |                                       |                 |
|----------------------------------------------------------------------------------------------------------------|------------------------------------|-----------------|---------------------------------------|-----------------|
| <b>Ecological climate zones</b>                                                                                | <b>Litter (tC ha<sup>-1</sup>)</b> |                 | <b>Dead wood (tC ha<sup>-1</sup>)</b> |                 |
|                                                                                                                | <b>deciduous</b>                   | <b>conifers</b> | <b>deciduous</b>                      | <b>conifers</b> |
| Boreal Dry Tundra Woodland                                                                                     | 31                                 | 69              | 5.7                                   | 1.3             |
| Cool Temperate Moist Mountain System                                                                           | 6                                  | 8               | 21.2                                  | 48.1            |
| Cool Temperate Dry Steppe                                                                                      | 40                                 | 31              | 26.2                                  | 8               |
| Cool Temperate Oceanic Forest                                                                                  | 6                                  | 7               | 36.8                                  | 36.8            |
| Cool Temperate Continental Forest                                                                              | 27                                 | 70              | 23.6                                  | 22.1            |

No change in DOM is considered for conversions from cropland, grassland, and wetlands to settlements, and the notation key NO is applied.

#### 6.8.2.1.3 Mineral soil (key category)

The source category mineral soil on land converted from forest land, and cropland to settlements are identified as key categories for Level assessment 1990, Level assessment 2021 and Trend assessment 1990 - 2021 according to Approach 2 key category analysis (see Table 6.6).

The same Tier 1 Approach 3 methodology described in detail by Bárcena et al. (2021) for lands converted to forest land is also applied here (see section 6.4.2), with modifications to account for emissions specified for the settlement subdivision classes.

The area proportion of each subdivision class occurring on the plot is then assigned a Tier 1 stock change factor ( $SCF = F_{LU} \cdot F_{MG} \cdot F_I$ ) (Table 6.37). Individual NFI plot areas can contain one or more subdivision classes, to which the appropriate default  $F_{LU}$ ,  $F_{MG}$ , and  $F_I$  value are applied to the appropriate portion of non-greenspace and greenspace parts occurring on the plot (Table 6.37).

For infrastructure and paved-over areas, IPCC 2006 states that the product of  $F_{LU}$ ,  $F_{MG}$  and  $F_I$  should be 0.8 (we have assigned this to  $F_{LU}$ , keeping  $F_{MG}$  and  $F_I$  1.0). Factors for turfgrass and vegetated are based on IPCC 2019 Refinement, Vol. 4, Ch. 6, Table 6.2. IPCC 2006

Guidelines state that for the proportion of the settlement area that is wooded, assume all stock change factors equal 1 (thus  $F_{LU}$ ,  $F_{MG}$  and  $F_I$  all equal 1.0) in Tier 1. Greenspace area with at least one tree present is considered wooded.

**Table 6.37 Lands converted to settlements subdivision classes and their associated Tier 1 stock change factors for mineral soils.**

| Classes            | Mineral soils |      |     |
|--------------------|---------------|------|-----|
|                    | FLU           | FMG  | FI  |
| Infrastructure (I) | 0.8           | 1.0  | 1.0 |
| Paved (P)          | 0.8           | 1.0  | 1.0 |
| Turfgrass (T)      | 1.0           | 1.14 | 1.0 |
| Vegetated (V)      | 1.0           | 1.0  | 1.0 |
| Wooded (W)         | 1.0           | 1.0  | 1.0 |

The national mean mineral soil CSC rate for lands converted to settlement can be found in Table 6.38.

**Table 6.38 Annual mineral soil carbon stock change rates (mean  $\pm$  standard deviation in  $t\ C\ ha^{-1}\ yr^{-1}$ ) for lands converted to settlement (1990 – 2021).**

| IPCC climate region  | Cropland        | Forest land        | Intensive Grassland | Extensive Grassland | Unmanaged Wetlands (waterbody) |
|----------------------|-----------------|--------------------|---------------------|---------------------|--------------------------------|
| Boreal Dry           |                 | -0.661             |                     |                     |                                |
| Cool Temperate Dry   |                 | -0.039 $\pm$ 0.044 |                     |                     |                                |
| Cool Temperate Moist | 0.53 $\pm$ 0.69 | -0.32 $\pm$ 0.37   | -0.25 $\pm$ 0.51    | -0.32 $\pm$ 0.37    | -0.218 $\pm$ 0.2               |

#### 6.8.2.1.4 Organic soil (key category)

The source category organic soil on land converted from forest land, cropland and unmanaged wetlands to settlements are identified as key categories for Level assessment 1990, Level assessment 2021 and/or Trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6).

CO<sub>2</sub> emission from drained organic soils on forest land converted to settlements was identified as a key category.

In the IPCC 2006 Guidelines, Vol. 4, Ch. 8, it is stated that: *"If the peat is removed the carbon should be assumed to be released in the year of removal"*. Thus, for the category infrastructure, where we assume all peat to be removed, we calculate instant oxidation with emissions of CO<sub>2</sub>. We apply different factors for instant oxidation (Table 6.39) according to soil depth classes (Stokland et al. manuscript). Depth classes of the organic soil were available from NFI and old map products (AR5, "Markslagskart") and are described: shallow 0.4-1 m; deep > 1 m. Instant oxidation of shallow and deep organic soils results in the loss of 32.13 kg C m<sup>-2</sup> and 91.8 kg C m<sup>-2</sup>, respectively. They are based on a carbon density of 45.9 kg C/m<sup>2</sup> and an average depth of 0.7 m for shallow bogs and 2.0 m for deep bogs.

According to the IPCC 2013 Wetlands supplement, it is *"good practice to take the default EF of the land-use category that is closest to national conditions of drained organic soils under Settlements"*. We have allocated the relevant IPCC 2013 Wetlands supplement default EFs to the different subdivision classes where organic soil is drained and not removed (as described in Table 6.39).

| <b>Table 6.39 Settlements subdivision classes and their associated Tier 1 EF's on organic soils. EF for CO<sub>2</sub> (tC ha<sup>-1</sup> yr<sup>-1</sup>) is from Table 2.1 in IPCC 2014b</b> |                                              |                                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-------------------------------------------|
| <b>Classes</b>                                                                                                                                                                                  | <b>C (t ha<sup>-1</sup> yr<sup>-1</sup>)</b> | <b>IPCC land use category<sup>2</sup></b> |
| <b>Infrastructure (I)<sup>1</sup></b>                                                                                                                                                           |                                              |                                           |
| <b>Shallow (0.4 – 1 m)</b>                                                                                                                                                                      | 321.3                                        |                                           |
| <b>Deep (&gt; 1 m)</b>                                                                                                                                                                          | 918.0                                        |                                           |
| <b>Temperate climate zone</b>                                                                                                                                                                   |                                              |                                           |
| <b>Paved (P)</b>                                                                                                                                                                                | 3.6                                          | Grassland, shallow-drained, nutrient-rich |
| <b>Turfgrass (T)</b>                                                                                                                                                                            | 6.1                                          | Grassland, deep-drained, nutrient-rich    |
| <b>Vegetated (V)</b>                                                                                                                                                                            | 3.6                                          | Grassland, shallow-drained, nutrient-rich |
| <b>Boreal climate zone</b>                                                                                                                                                                      |                                              |                                           |
| <b>Paved (P)</b>                                                                                                                                                                                | 5.7                                          | Grassland, drained                        |
| <b>Turfgrass (T)</b>                                                                                                                                                                            | 5.7                                          | Grassland, drained                        |
| <b>Vegetated (V)</b>                                                                                                                                                                            | 5.7                                          | Grassland, drained                        |

<sup>1</sup> *These emissions are from instant oxidation and are only applied once for the initial transition.*

<sup>2</sup> *We do not have information available to separate nutrient rich and nutrient poor and assume all temperate plots to be nutrient rich. For boreal climate zone default EFs is not differentiated between deep or shallow drained.*

### **6.8.2.2 *Uncertainties and time-series consistency***

Uncertainties are shown in Table 6.3 for living biomass and DOM and in Table 6.4 for organic and mineral soils. The time-series was consistently calculated.

### **6.8.2.3 *QA/QC and verification***

The QA/QC plan was performed according to the Tier 1 procedure.

### **6.8.2.4 *Recalculations***

Organic soil emission estimates had the largest changes for lands converted to settlements in 2021 due to a new observation from cropland to settlements. Other carbon stock changes were mainly due to updated extrapolation and minor changes in the database classification.

See chapter 10.2.4. for details.

### **6.8.2.5 *Planned improvements***

Living biomass, dead organic matter, mineral soils, and organic soils

No planned improvements.

## **6.8.3 *Completeness***

The reporting for emissions and removals occurring on settlements is complete.

## **6.9 Other land – 4F**

The land use category other land covers approximately 11% of the total land area in Norway and reflects a large amount of mountainous and rocky terrain. There were no land-use changes to other land in NIR 2023. No C stock change (CSC) occurred on other lands. It is only mandatory to report CSC for land converted to other land.

### **6.9.1 *Other land remaining other land, 4F1***

Reporting of emissions from other land remaining other land is not mandatory. Other land in Norway are wasteland areas with bare soil, rocks, and ice with no significant C pools.

### **6.9.2 *Land converted to other land, 4F2***

There were no land-use changes to other land in NIR 2023, and all C stock change is reported as NO.

#### **6.9.2.1 Methodological issues**

The area estimates are based on NFI data.

#### **6.9.2.2 Uncertainties and time-series consistency**

Area uncertainties are estimated as described in section 6.1.3.

#### **6.9.2.3 QA/QC and verification**

The QA/QC plan was performed according to the Tier 1 procedure.

#### **6.9.2.4 Recalculations**

There have been no recalculations performed for this source category this year.

#### **6.9.2.5 Planned improvements**

There are no planned improvements.

### **6.9.3 Completeness**

The reporting for emissions and removals occurring on other land is complete.

## **6.10 Harvested wood products – 4G (key category)**

Harvested wood products (HWP) is identified as a key category by level assessments 1990 and 2021, and trend assessment 1990 – 2021 according to Approach 2 key category analysis (see Table 6.6).

HWP prolong the period carbon is bound in timber after it is removed from the forest. The HWP accounting includes the carbon pool inflow in sawnwood, wood-based panels, and paper and paperboard. HWP does not include all wood material that leaves the harvest site, only those parts of the harvest used for the three abovementioned default HWP categories. According to the current calculation approach, the total HWP pool was 1000 kt CO<sub>2</sub> in the base year 1990.

Net annual removals from HWP in use in 2021 were -44 kt CO<sub>2</sub> for HWP produced and consumed domestically, and -446 kt CO<sub>2</sub> for HWP produced and exported. In 2021, the total removals from the HWP pool were -490 kt CO<sub>2</sub>.

In the period 2009-2016, there was a clear trend toward less storage (see Figure 6-1) in the HWP pool. A similar trend was found for other European countries, including the peak in the period around 2008-2010. In 2017, 2018, 2019, 2020 and 2021, the total of HWP categories again provided removals. The contribution from the individual categories has been: -501 kt CO<sub>2</sub> (-490 in 2020, -515 in 2019, -508 in 2018, -415 in 2017), wood-based panels 10 kt CO<sub>2</sub> (44 kt CO<sub>2</sub> in 2020, 12 kt CO<sub>2</sub> in 2019, 22 kt CO<sub>2</sub> in 2018, 35 CO<sub>2</sub> in 2017),

paper and paperboard 262 kt CO<sub>2</sub> (-4 in 2020, 29 in 2019, 104 in 2018, 144 in 2017). Hence, the main contribution to total HWP removals was from sawnwood, while the total HWP emissions were from paper and paperboard.

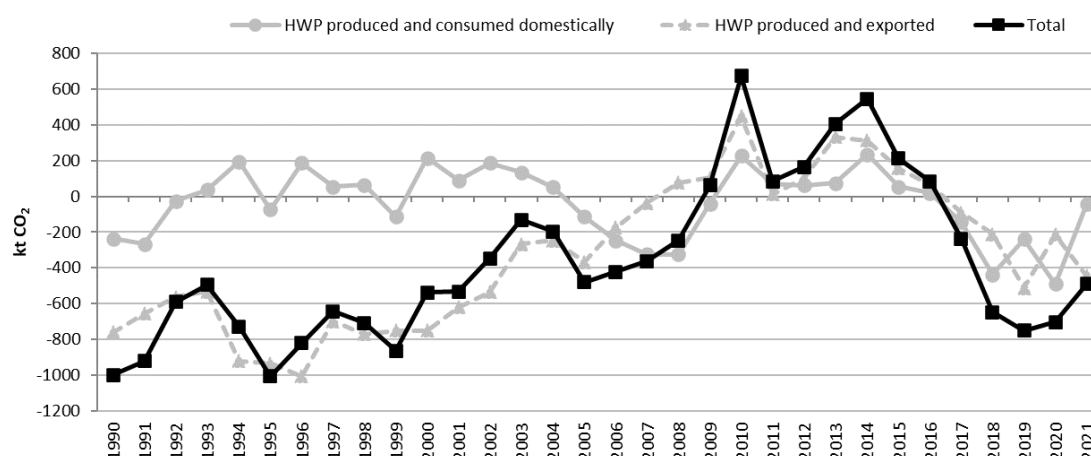


Figure 6-22 CO<sub>2</sub> emissions and removals in HWP (kt CO<sub>2</sub>). Source: Norwegian Institute of Bioeconomy Research.

## 6.10.1 Methodological issues

### 6.10.1.1 Choice of method

Emissions and removals reported for HWP are estimated using a Tier 2 method. The calculations are based on chapter 2.8 in the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a). The IPCC 2013 KP supplement approach fulfils the requirements in footnote 12 of CRF Table 4.Gs.1. The Tier 2 default options are applied, including the three default HWP categories sawnwood, wood-based panels, and paper and paperboard and their associated half-lives and conversion factors (IPCC 2014a).

To improve transparency and be in accordance with CRF Table 4.Gs.1, the Norwegian estimates differentiate between domestically produced and consumed HWP and wood products that are produced and exported.

The activity data used starts in 1961 and is based on FAO statistics. Calculations have been performed using data from 1961 to 2021. We calculated the historic pool from 1950 – 1960 according to IPCC (2014a). Only emissions from 1990 and onwards are reported.



The estimation of C stocks (C) and annual carbon stock changes ( $\Delta C$ ) for each HWP category was estimated using Equation 2.8.5 (IPCC 2014a)

$$C(i+1) = e^{-k} \times C(i) + \left[ \frac{(1 - e^{-k})}{k} \right] \times Inflow(i)$$

$$\Delta C(i) = C(i+1) - C(i)$$

where  $i$  = year;  $C(i)$  = the carbon stock (kt C) in the particular HWP category at the beginning of year  $i$ , with  $i = (1961, \dots, 2021)$ , but only emission estimates for  $i = (1990, \dots, 2021)$  are reported;  $k$  is the decay constant for the first-order decay for HWP category (i.e. sawnwood, wood-based panels or paper and paperboards) given in units  $\text{year}^{-1}$  as  $k = \ln(2)/HL$ , where HL is the half-life of the HWP pool, which is constant and given in the unit years.  $Inflow(i)$  = the inflow to the particular HWP category during year  $i$ ;  $\Delta C(i)$  = carbon stock change of the HWP category during year  $i$ , kt C  $\text{year}^{-1}$ .

The approximation of the carbon stocks in HWP pools at initial time  $C(i = t_0 = 1961)$  was calculated according to Equation 2.8.6

$$C_{(t_0)} = \frac{Inflow_{average}}{k}$$

where

$$Inflow_{average} = \frac{(\sum_{i=t_0}^{t_4} Inflow(i))}{5}$$

The C stock changes for each of the three HWP categories (sawnwood, wood-based panels, paper and paperboard) were estimated and summed to provide the total for Norway.

#### 6.10.1.2 Activity data

All the activity data are from the FAO forestry statistics.<sup>37</sup> The initial unit is  $\text{m}^3$ , except for the 'pulp for paper' and 'paper and paperboard', where the unit is the metric ton. Carbon conversion was performed using the default conversion factors given by the IPCC (IPCC 2014a). Exported and domestically consumed HWP is calculated and reported separately. The domestically produced and consumed inflow data are based on consumption (Production – Export). Imported HWP is not included in the calculations (Production approach).

#### 6.10.1.3 Assumptions

It is assumed that the Tier 2 method reflects the carbon flow in the HWP pool. The assumption of first-order decay (i.e. exponential decay) implies that loss from the stock of products is estimated as a constant fraction of the amount of stock (IPCC 2006).

<sup>37</sup> <http://www.fao.org/faostat/en/#data/FO>

It is assumed that the default half-lives are representative values for Norway.

#### **6.10.2 Uncertainties and time-series consistency**

The reported uncertainty estimates for half-lives are  $\pm 50\%$ , according to IPCC (2006). According to the IPCC 2013 KP Supplement (IPCC 2014a), an overall estimate of the HWP activity data (i.e., sawnwood, wood-based panels, and paper and paperboard) from, e.g., FAO result in an estimated uncertainty of the reported values between  $-25\%$  to  $+5\%$ .

#### **6.10.3 QA/QC and verification**

The QA/QC plan was performed according to the Tier 1 procedure.

#### **6.10.4 Recalculations**

Each year, when new activity data are added from the FAO database, the activity data for the previous five years are checked and updated, if needed. The activity data used as data for inflow for 2021 was updated.

See chapter 10.2.4 for details.

#### **6.10.5 Planned improvements**

No planned improvements.

#### **6.10.6 Completeness**

The reporting for emissions and removals from harvested wood products is complete.

### **6.11 Direct N<sub>2</sub>O emissions from managed soils – 4(I)**

Direct N<sub>2</sub>O emissions from managed soils are estimated from N inputs of inorganic and organic origin. N inputs from inorganic N fertilizer applied to forest land are reported. Inorganic fertilizer is not applied to managed wetlands and is reported as NO. Any inorganic fertilizer applied in the land use category settlements is included in the agriculture sector and reported as IE in the LULUCF CRF tables. Emissions from the use of organic fertilizers on settlements are reported. Livestock is generally not grazing managed wetlands (peat extraction areas, mires with ditches and flooded lands), and direct N<sub>2</sub>O emissions are hence reported as NO. N inputs from organic and inorganic N fertilizers on cropland and grassland are reported as IE and included in the agriculture sector.

#### **6.11.1 Inorganic fertilizer on forest land**

N<sub>2</sub>O is produced in soils as a by-product of nitrification and denitrification. Fertilizer input is particularly important for this process. However, fertilization of forest land has been limited in Norway. The area fertilized was 24 km<sup>2</sup> in 1990, and the area and the net amount of N applied decreased during the inventory period. From 2016 to 2021, however, the

fertilized areas increased to 84, 91, 56, 38, 44, and 45 km<sup>2</sup> due to a new subsidy scheme. This led to an increase in the net amount of N applied after 2015 (Table 6.35).

**Table 6.40 Estimated emissions from fertilization of forest land 1990-2021.**

| Year | Fertilizer input (t N) |              | Net amount N applied (t N) | N <sub>2</sub> O emissions (t N <sub>2</sub> O) |
|------|------------------------|--------------|----------------------------|-------------------------------------------------|
|      | Mineral soil           | Organic soil |                            |                                                 |
| 1990 | 177.1                  | 59.0         | 236.1                      | 7.4                                             |
| 1991 | 325.7                  | 66.4         | 392.2                      | 12.3                                            |
| 1992 | 253.4                  | 102.2        | 355.7                      | 11.2                                            |
| 1993 | 181.0                  | 66.4         | 247.4                      | 7.8                                             |
| 1994 | 169.0                  | 66.4         | 235.4                      | 7.4                                             |
| 1995 | 160.3                  | 59.8         | 220.2                      | 6.9                                             |
| 1996 | 198.9                  | 36.5         | 235.4                      | 7.4                                             |
| 1997 | 232.5                  | 19.4         | 251.8                      | 7.9                                             |
| 1998 | 242.6                  | 22.6         | 265.2                      | 8.3                                             |
| 1999 | 217.8                  | 43.6         | 261.3                      | 8.2                                             |
| 2000 | 134.7                  | 21.6         | 156.3                      | 4.9                                             |
| 2001 | 153.6                  | 19.1         | 172.7                      | 5.4                                             |
| 2002 | 178.5                  | 8.4          | 186.8                      | 5.9                                             |
| 2003 | 85.4                   | 1.2          | 86.7                       | 2.7                                             |
| 2004 | 75.5                   | 2.3          | 77.8                       | 2.4                                             |
| 2005 | 52.9                   | 31.4         | 84.3                       | 2.7                                             |
| 2006 | 33.6                   | 4.0          | 37.5                       | 1.2                                             |
| 2007 | 81.2                   | 0.6          | 81.9                       | 2.6                                             |
| 2008 | 105.7                  | 0.9          | 106.6                      | 3.3                                             |
| 2009 | 113.1                  | 0.6          | 113.7                      | 3.6                                             |
| 2010 | 72.8                   | 0.1          | 73.0                       | 2.3                                             |
| 2011 | 84.6                   | 0.0          | 84.6                       | 2.7                                             |
| 2012 | 111.9                  | 0.1          | 112.0                      | 3.5                                             |
| 2013 | 170.2                  | 0.2          | 170.4                      | 5.4                                             |
| 2014 | 59.3                   | 0.0          | 59.3                       | 1.9                                             |
| 2015 | 91.2                   | 0.0          | 91.2                       | 2.9                                             |
| 2016 | 1235.6                 | 0.0          | 1235.6                     | 38.8                                            |
| 2017 | 1350.0                 | 0.0          | 1350.0                     | 42.4                                            |
| 2018 | 838.8                  | 0.0          | 838.8                      | 26.4                                            |
| 2019 | 557.8                  | 0.0          | 557.8                      | 17.5                                            |

|      |       |     |       |      |
|------|-------|-----|-------|------|
| 2020 | 648.2 | 0.0 | 648.2 | 20.4 |
| 2021 | 663.1 | 0.0 | 663.1 | 20.8 |

### 6.11.1.1 Methodological issues

#### 6.11.1.1.1 Choice of method

The estimate is based on a Tier 1 method with a default emission factor. Emissions are calculated according to

$$N_2O_{direct-N_{fertilizer}} = F_{SN} \times EF \times 44/28$$

where  $F_{SN}$  is the annual amount of synthetic fertilizer nitrogen applied (kt N) to forest soil and EF is the emission factor for  $N_2O$  emissions from N inputs, kg  $N_2O$ -N/kg N input.

#### 6.11.1.1.2 Activity data

Statistics Norway supplied unpublished data on the application of synthetic fertilizer. The statistics include the area applied with fertilizer and the amounts and types of fertilizer applied for 1995 – 2015. However, only the area and amount of fertilizer applied are available for 2016 – 2021 due to a change in the data acquisition procedures. For the period 1990 – 1994, only data for the total fertilized area is available. Data from 1995 – 2004 were used to estimate the amount of N-fertilizer applied for the period 1990 – 1994.

The amount of fertilizer applied is given as the total weight. The nitrogen content depends on the type of fertilizer. Yara supplied sales numbers for forest fertilization. From 1993 to 1994 and onwards, calcium ammonium nitrate-based fertilizer dominated the market for fertilization of forests on mineral soils (Ole Stampe - Yara Norge AS, personal communication, 2013). The N-content of calcium ammonium nitrate is 27% (weight percent).

#### 6.11.1.1.3 Emission factor

The default emission factor is 1% of applied N (IPCC 2006 Guidelines, Vol. 4, Ch. 11, Table 11.1). The emission factor is highly uncertain, with an uncertainty range from 0.003 to 0.03 (IPCC 2006).

### 6.11.2 Organic fertilizer on forest land

In Norway, livestock may graze in forests during the summer months. Emissions from organic N fertilizer applied by animal manure when livestock graze in the forest land remaining forest land and land converted to forest land are reported with the notation key IE and emissions are reported in the agriculture sector.

### 6.11.3 Organic fertilizer on settlements

Direct N<sub>2</sub>O emissions from applying organic N fertilizer in settlements have been reported in the LULUCF sector since NIR 2015. Prior to 2015, emissions from the application of sewage sludge on urban lawns, road-side grass-strips, and parks were reported in the waste sector. Emissions have increased slightly from 0.0090 kt N<sub>2</sub>O yr<sup>-1</sup> in 1990 to 0.0234 kt N<sub>2</sub>O yr<sup>-1</sup> in 2021 (2.4 to 6.2 kt CO<sub>2</sub> eq yr<sup>-1</sup>).

#### 6.11.3.1 Methodological issues

##### 6.11.3.1.1 Choice of method

A Tier 1 method was used, applying the default emission factor (IPCC 2006). To derive N inputs from organic fertilizer, the total dry matter amount of all types of sewage sludge applied was multiplied by an N content of 2.82% (Statistics Norway 2001).

##### 6.11.3.1.2 Activity data

Data on sewage sludge's total amount (dry matter) are derived from Statistics Norway and cover the following distribution types: parks and green areas, soil fertilizer production, cover on landfills, other use, and unknown use. The data is collected every year by SSB, and a consistent time series from 1990 was available.

### 6.11.4 Uncertainties

The IPCC provides the uncertainty related to the default emissions factor for N<sub>2</sub>O from N additions from mineral and organic fertilizer in the range of 0.003 - 0.03, equal to  $\pm 200\%$ . In addition, we assume that the activity data have  $\pm 20\%$  uncertainty associated with the estimation of inorganic N applied to forest land and organic N applied to settlements. The activity data and the method used to estimate the organic N input to forest land are more uncertain, and an error of  $\pm 50\%$  was assumed. The total uncertainties (of the emission factor, activity data, and method) were used in the KCA for each source. The combined uncertainty is shown in Table 6.5.

### 6.11.5 QA/QC and verification

The QA/QC plan was performed according to the Tier 1 procedure.

### 6.11.6 Recalculations

N<sub>2</sub>O emission from direct forest fertilization was erroneously given as N-N<sub>2</sub>O emission. Correction induced a general increase of the estimates by a factor of 3.14 (i.e. 44/14). See chapter 10.2.4 for details.

### 6.11.7 Planned improvements

A late revision revealed that the correction factor used in the recalculations (3.14, i.e. 44/14) is also incorrect and should have been equal to 1.57 (i.e., 44/28). This new correction factor will be implemented next year, as the error is very small relative to the total emissions from the non-LULUCF sectors (approximately 0.0054%).

### 6.11.8 Completeness

The reporting for Direct N<sub>2</sub>O emissions from managed soils is complete.

## 6.12 Emissions and removals from drainage, rewetting and other management of soils – 4(II)

Rewetting of organic and mineral soils is not practised on a large scale in Norway, and drainage and rewetting (WDR) is not an elected KP activity. Thus, in CRF Table 4(II), we report only emissions from drained organic soils (including peat extraction) as these are mandatory to report. CO<sub>2</sub> emissions from drained organic soils are reported as IE in CRF Table 4(II) because they are included in CRF Tables 4.A-4.E as C stock changes in the organic soils pool. In CRF Table 4(II), we report CH<sub>4</sub> and N<sub>2</sub>O emissions from forest land, drained wetlands used for peat extraction, and other drained wetlands (mires). Further, we report N<sub>2</sub>O and CH<sub>4</sub> emissions on subcategories of settlements which have organic soil. For croplands and intensive grasslands, only CH<sub>4</sub> emissions are reported. Rewetting of mineral and organic soils on forest land, cropland, grassland, and wetlands (except for rewetted mineral soils reported as NO) is reported as NE. According to the IPCC 2006 Guidelines, N<sub>2</sub>O emissions from drained organic agricultural soils (cropland and grassland) are reported in the agriculture sector.

N<sub>2</sub>O and CH<sub>4</sub> emissions from instant oxidation of removed peat on settlements are not reported due to no default method available.

N<sub>2</sub>O emissions from drained organic soils from forest land is a key category in the 1990 and 2021 level assessments and trend assessment. CH<sub>4</sub> emissions from drained organic soils from cropland is a key category in the 1990 and 2021 level assessments.

Please note that CRF tables *Table4* and *Summary2* are inconsistent due to some emissions of CH<sub>4</sub> and N<sub>2</sub>O that cannot be reported in the CRF by detailed area types, according to footnote 4 in CRF Table 4(II) and Table 4(IV). These emissions are entered into the tables only at more aggregated levels. The level of reporting is due to properties of the CRF

system, follows decision 24/CP.19, and is not caused by a lack of data in the Norwegian emission inventory. The UNFCCC Secretariat did confirm the inconsistency in the sums of the subtotals in 2015.

### 6.12.1 N<sub>2</sub>O emissions from drainage of organic soils (key category)

The source category N<sub>2</sub>O emissions from drained organic soils on forest land is identified as a key category for Level assessment 1990 and Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).

#### 6.12.1.1 Methodological issues

To estimate N<sub>2</sub>O emission from drained organic soils on all land uses, we use a Tier 1 method based on the IPCC 2006 Guidelines. The area is multiplied by an emission factor. To use the most recent scientific knowledge, we apply the emission factors from the IPCC 2013 Wetlands supplement.

##### 6.12.1.1.1 Activity data

See section 6.1.5.1. For croplands and intensive grasslands, N<sub>2</sub>O is reported in the agriculture sector (thus not in LULUCF).

##### 6.12.1.1.2 Emissions factors

All drained organic soils found on forest lands and wetlands were located in the cool temperate climate zone. The default emission factor for forest land in temperate climate from the IPCC 2013 Wetlands supplement was used (2.8 kg N<sub>2</sub>O-N ha<sup>-1</sup> yr<sup>-1</sup>). N<sub>2</sub>O emissions from wetlands used for peat extraction were estimated with the emission factor of 0.3 kg N<sub>2</sub>O-N yr<sup>-1</sup> (IPCC 2014b); see Table 6.31.

EFs for drained organic soils on settlements are shown in table Table 6.41.

### 6.12.2 CH<sub>4</sub> emissions from drainage of organic soils (key category)

The source category CH<sub>4</sub> emissions from drained organic soils on cropland is identified as a key category for Level assessment 1990 and Level assessment 2021 according to Approach 2 key category analysis (see Table 6.6).

#### 6.12.2.1 Methodological issues

To estimate CH<sub>4</sub> emissions, we used the Tier 1 method applying the EFs of the IPCC 2013 Wetlands supplement. The method accounts for methane fluxes both in the drainage ditches and on the land using the following equation

$$\text{CH}_4 = A \times ((1 - \text{Frac}_{\text{ditch}}) \times \text{EFCH}_{4\_land} + \text{Frac}_{\text{ditch}} \times \text{EFCH}_{4\_ditch})$$

where,  $A$  is the area of drained organic soil;  $\text{Frac}_{\text{ditch}}$  is the fraction of the area occupied with ditches; and  $\text{EFCH}_{4,\text{land}}$   $\text{EFCH}_{4,\text{ditch}}$  are the emissions factor for the land and the ditch, respectively.

NFI registration of ditches (see activity data below) allowed the estimation of a mean national value for the  $\text{Frac}_{\text{ditch}}$  of 6% for forest land and 4% for wetlands. There is no information available in Norway to provide an accurate estimate for the fraction of ditches for cropland, grassland, settlements and for peat extraction and the default value of 5% is used (IPCC 2014b).

#### 6.12.2.1.1 Activity data

The drained forest soil and wetlands area was from registrations 2016-2021 in the Norwegian NFI, as described in section 6.4.1.

The land area under peat extraction was estimated as described in section 6.7.1.

All areas of organic soil under settlements are assumed to be drained.

For cropland and grasslands, the estimated areas of drained organic soils were as described in section 6.5.1 and section 6.6.1, and the areas of land converted to cropland and grassland, respectively, are also included in these estimates.

#### 6.12.2.1.2 Emission factor

For drained forests and wetlands on organic soils, the default  $\text{EFCH}_{4,\text{land}}$  in the temperate climate zone from the IPCC 2013 Wetlands supplement is used ( $2.5 \text{ kg CH}_4 \text{ yr}^{-1}$ ). For cropland, the  $\text{EFCH}_{4,\text{land}}$  is 0; for grassland, we used the factor for shallow-drained, nutrient-rich grassland of  $39 \text{ kg CH}_4 \text{ yr}^{-1}$ . The emission factor for peat extraction on wetlands is  $6.1 \text{ kg CH}_4 \text{ yr}^{-1}$  for the temperate and boreal climate zone (Table 6.31). For settlements, factors are given in Table 6.41 depending on sub-categories.

The emission factors for  $\text{CH}_4$  from the ditches or drains ( $\text{EFCH}_{4,\text{ditch}}$ ) were  $217 \text{ kg CH}_4 \text{ yr}^{-1}$  for drained organic soils on forest land and wetlands,  $1165 \text{ kg CH}_4 \text{ yr}^{-1}$  for cropland and  $527 \text{ kg CH}_4 \text{ yr}^{-1}$  for grassland, and  $542 \text{ kg CH}_4 \text{ yr}^{-1}$  for peat extraction land. For drained organic soil in settlements, factors are given in Table 6.41 depending on sub-categories.

**Table 6.41 Settlements subdivision classes and their associated Tier 1 EF's on organic soils.**  
EF for  $\text{CH}_4$  and  $\text{N}_2\text{O}$  are from Table 2.3, 2.4, and 2.5 in IPCC 2014b

| Classes                       | $\text{kg N}_2\text{O-N ha}^{-1}\text{yr}^{-1}$ | $\text{kg CH}_4 \text{ ha}^{-1}\text{yr}^{-1}$ | $\text{kg CH}_4 \text{ ha}^{-1}\text{yr}^{-1}$ drainage ditches | Frac ditch |
|-------------------------------|-------------------------------------------------|------------------------------------------------|-----------------------------------------------------------------|------------|
| <b>Temperate Climate Zone</b> |                                                 |                                                |                                                                 |            |
| Paved (P)                     | 1.6                                             | 39                                             | 527                                                             | 0.05       |



|                            |     |    |      |      |
|----------------------------|-----|----|------|------|
| Turfgrass (T)              | 8.2 | 16 | 1165 | 0.05 |
| Vegetated (V)              | 1.6 | 39 | 527  | 0.05 |
| <b>Boreal Climate Zone</b> |     |    |      |      |
| Paved (P)                  | 1.6 | 39 | 527  | 0.05 |
| Turfgrass (T)              | 8.2 | 16 | 1165 | 0.05 |
| Vegetated (V)              | 1.6 | 39 | 527  | 0.05 |

### 6.12.3 Uncertainties

The uncertainties associated with the emission factors of the IPCC 2013 Wetlands supplement are summarized in Table 6.5.

To derive the total uncertainty of the emission estimate, we aggregated the uncertainty for the emission factor and the area estimate, respectively. Uncertainties for areas (for all categories relevant to organic drained managed soils) are derived from the sampling errors in the NFI. We assumed 100% for the area with peat extraction. Uncertainties for emissions in drained organic soils in settlements were determined by weighing each IPCC uncertainty by the magnitude of the respective EF.

### 6.12.4 QA/QC and verification

The QA/QC plan was performed according to the Tier 1 procedure. Methodology for organic soil on settlements was subject to external quality assurance in 2021.

### 6.12.5 Recalculations

All observed changes were contributed by updates in the NFI database and extrapolation.

See chapter 10.2.4 for details.

### 6.12.6 Planned improvements

Drained organic soils

No planned improvements.

### 6.12.7 Completeness

The reporting for emissions and removals from drainage and rewetting of organic and mineral soils is complete. The likely level of emissions from lands converted to peatland extraction (all gasses) was estimated and tested for non-significance. See section 6.7.3. We report NE.

## 6.13 Direct N<sub>2</sub>O emissions from N mineralization and immobilization – 4(III)

In the IPCC 2006 Guidelines, direct N<sub>2</sub>O emissions are estimated from N mineralization-immobilization turnover associated with loss of soil organic matter resulting from the change of land use or management of mineral soils on all types of land use. We estimate N<sub>2</sub>O losses from all land uses that have negative C stock changes in the mineral soil pool, and the areas reported in CRF Table 4(III) correspond to the areas with negative C stock changes and not the total area for all land-use conversions.

### 6.13.1 Methodological issues

#### 6.13.1.1 Choice of method

To estimate N<sub>2</sub>O emissions from N mineralization, we first calculate the net annual amount of N mineralized in mineral soils resulting from SOC loss ( $F_{SOM}$ ) from

$$F_{SOM} = \Delta C \times 1 / CN \quad \text{Equation 11.8; (IPCC 2006)}$$

where  $\Delta C$  is the average annual C loss from mineralization of soil for each land-use type (in kt C yr<sup>-1</sup>), and CN is the C/N ratio of cropland soils. To estimate the N<sub>2</sub>O emissions from N mineralization, we multiply  $F_{SOM}$  with the default emission factor (EF = 0.01 kg N<sub>2</sub>O-N (kgN<sup>-1</sup>)). We consider the method a Tier 1 because we used the default C/N ratio (CN = 15), although most SOC losses were derived using a Tier 2 method.

Certain land-uses and land-use changes (e.g., settlements converted to forest land) result in positive SOC stock changes in the mineral soil pool, thus, no N<sub>2</sub>O emissions are reported from these sub-categories.

#### 6.13.1.2 Activity data

Activity data used for this source is the annual average C losses, which are those reported in the C stock change CRF Tables 4.A-4.F for each land-use class. The C stock change is estimated as described under the mineral soil pool for each land-use class.

### 6.13.2 Recalculations

All observed changes were mainly due to updates in the NFI area and extrapolation.

Additionally, the change in the rounding of decimals for grassland remaining grassland (see section 6.6.1.4) will result in changes also for N<sub>2</sub>O emissions from N-mineralization/immobilization.

See chapter 10.2.4 for details.

### 6.13.3 Planned improvements

No planned improvements.

#### 6.13.4 Completeness

Reporting from source 4(III) Direct N<sub>2</sub>O emissions from N mineralization and immobilization is complete.

### 6.14 Indirect N<sub>2</sub>O emissions from managed soils – 4(IV)

Indirect N<sub>2</sub>O emissions occur through two pathways: 1) the volatilization of N as NH<sub>3</sub> and NO<sub>x</sub> and subsequent deposition of N compounds (atmospheric deposition), and 2) the leaching and runoff of N from land that has been subjected to excess N application from organic or inorganic fertilizers, as well as N mineralized due to soil C loss. CRF Table 4(IV) has two sub-categories 1) atmospheric deposition and 2) nitrogen leaching and runoff.

The IPCC 2006 Guidelines methodology for estimating indirect emissions includes N inputs from several sources (Equations 11.9 and 11.10). However, the sources are split between the reporting in the LULUCF and the agriculture sector. The indirect emissions reported in the LULUCF sector under atmospheric deposition are derived from the N inputs coming from synthetic N fertilizer on forest land ( $F_{SN}$ ) and organic N fertilizer on forest land and settlements ( $F_{ON}$ ).

For the sub-category N leaching and runoff, N inputs arrive as synthetic and organic N fertilizers for atmospheric deposition, but also from N mineralization immobilization in mineral soils associated with loss of soil C ( $F_{SOM}$ ). Indirect emissions caused by N inputs from crop residues, urine and dung application from livestock, and N fertilizers on agricultural lands (cropland and grassland) are reported in the agriculture sector.

Please note that CRF Table 4 and summary 2 are inconsistent due to N<sub>2</sub>O from CRF Table 4(IV) not being included in the land use aggregations in CRF Table 4. The level of reporting is due to the properties of the CRF system and follows decision 24/CP.19 and is not caused by a lack of data in the Norwegian emission inventory. The UNFCCC Secretariat has confirmed the inconsistency in the sums of the subtotals.

#### 6.14.1 Atmospheric deposition

Indirect emissions reported under atmospheric deposition are estimated from synthetic N fertilizer input on forest land ( $F_{SN}$ ) and organic fertilizer N inputs on settlements ( $F_{ON}$ ).

##### 6.14.1.1 Methodological issues

###### 6.14.1.1.1 Method choice

We used the Tier 1 method of the IPCC 2006 Guidelines dictating that a fraction ( $Frac_{GASM}$  or  $Frac_{GASF}$ ) of the organic and inorganic N inputs ( $F_{ON}$  and  $F_{SN}$ ), respectively, are considered

volatilized and multiplied by the emission factor for atmospheric deposition (EF) according to

$$N_2O-N = (Frac_{GASF} \times F_{SN} + F_{ON} \times Frac_{GASM}) \times EF_{vol} \quad \text{Equation 11.9; (IPCC 2006).}$$

All parameters are default values:  $Frac_{GASM} = 0.2$ ,  $Frac_{GASF} = 0.1$ , and  $EF = 0.01 \text{ kg } N_2O-N \text{ (kg N)}^{-1}$ .

#### 6.14.1.1.2 Activity data

The N inputs from synthetic and organic N fertilizers were derived as described in section 6.11.

### 6.14.2 Nitrogen leaching and run-off

Indirect emissions from leaching and runoff were estimated from the N inputs of synthetic fertilizers on forest land and organic fertilizer on settlements and from N mineralized due to soil organic matter decomposition.

#### 6.14.2.1 Methodological issues

##### 6.14.2.1.1 Method choice

The Tier 1 method was applied where the fraction of all N added to the soils ( $Frac_{LEACH}$ ) is multiplied with the default emission factor  $EF_{leach} = 0.0075 \text{ kg } N_2O-N \text{ (kg N leaching/runoff)}^{-1}$  by

$$N_2O_{(L)}-N = (F_{SN} + F_{ON} + F_{SOM}) \times Frac_{LEACH} \times EF_{leach}$$

where  $F_{SN}$  is the N input from synthetic fertilizer,  $F_{ON}$  is the N input from organic fertilizer, and  $F_{SOM}$  is the input from N mineralized decomposition of mineral soils. We applied the default value for  $Frac_{LEACH}$  of 0.3.

##### 6.14.2.1.2 Activity data

The activity data were derived as described in section 6.11 for organic and inorganic fertilizer and section 6.13 for N mineralized during soil C loss.

### 6.14.3 Uncertainties

The uncertainty associated with the default emission factor for  $N_2O$  emissions from volatilization and deposition is  $\pm 400\%$  (IPCC 2006) and has a major influence on the emissions from atmospheric deposition. The EF for leaching has  $\pm 233\%$  uncertainty (IPCC 2006). In addition, the default values for the fraction of N that is volatilized from synthetic and organic fertilizer and the fraction lost by leaching have high uncertainties.

According to the IPCC 2006 Guidelines, the uncertainties are  $\pm 200\%$ ,  $\pm 150\%$ , and  $\pm 167\%$  for  $Frac_{GASF}$ ,  $Frac_{GASM}$ , and  $Frac_{LEACH}$ , respectively. Furthermore, the estimated N inputs ( $F_{SN}$ ,  $F_{ON}$ , and  $F_{SOM}$ ) also have uncertainties due to the activity data or methods mentioned in the

previous sections. Aggregating the individual uncertainties, we derive a total uncertainty of  $\pm 447\%$  for emissions due to atmospheric deposition and  $\pm 300\%$  from leaching and run-off (Table 6.5).

#### **6.14.4 QA/QC and verification**

The QA/QC plan was performed according to the Tier 1 procedure.

#### **6.14.5 Recalculations**

All observed changes were due to 4(I) and 4(III) updates, which are used as input data for calculating indirect  $\text{N}_2\text{O}$  emissions.

See chapter 10.2.4 of this document for details.

#### **6.14.6 Planned improvements**

There are no planned improvements.

#### **6.14.7 Completeness**

Reporting from source 4(IV) Indirect  $\text{N}_2\text{O}$  emissions from managed soils is complete.

### **6.15 Biomass Burning – 4(V)**

Emissions of  $\text{CO}_2$ ,  $\text{CH}_4$ , and  $\text{N}_2\text{O}$  due to biomass burning are reported for all land-use classes. For cropland and grassland, burning should be reported for woody biomass, which is not common in these land-use classes in Norway. Agroforestry is not normally practised, and woody biomass is found mostly in fruit tree orchards, which are generally not burned. Burning of woody biomass in wetlands, settlements, and other land does not occur either. We, therefore, report NO for all gasses in all land-use classes except for forest land.

Controlled fires on forest land are reported as NE as very few fire drills are performed, and we expect the emissions to be negligible (see below, the test of non-significance). Wildfires on grasslands are also reported as NE due to the lack of data and because emissions are considered negligible, as wildfires rarely occur on Norwegian grasslands (see below, the test of non-significance).

### 6.15.1 Fires on forest land

Prescribed burning of forests takes place in Norway only connected to firefighting rehearsals, comprising a very small area (approximately 5 ha and from 1 -7 fires annually). Thus, these emissions are reported as NE and assumed negligible. The area subject to wildfires varies considerably from year to year due to natural factors (e.g., variations in precipitation). According to the IPCC 2006 Guidelines, emissions of CO<sub>2</sub> from biomass burning in forest land remaining forest land need to be accounted for. However, these emissions are included in the estimate of C stock change in living biomass derived from the stock-change method. Hence, estimates of CO<sub>2</sub> emissions from wildfires are reported as IE.

#### 6.15.1.1 Methodological issues

##### 6.15.1.1.1 Choice of method

No national data on emission factors for non-CO<sub>2</sub> gases from forest fires exist. N<sub>2</sub>O and CH<sub>4</sub> emissions from forest wildfires are estimated using a Tier 1 method from the IPCC 2006 Guidelines. The following Equation 2.27 is used:

$$L_{\text{fire}} = A * M_B * C_f * G_{\text{ef}} * 10^{-3}$$

where  $L_{\text{fire}}$  = amount of greenhouse gas (CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) from fire (tonnes),  $A$  = area burnt (ha),  $M_B$  = mass of fuel available for combustion (tonnes ha<sup>-1</sup>),  $C_f$  = combustion factor (dimensionless), and  $G_{\text{ef}}$  = emission factor (g kg<sup>-1</sup> dry matter burnt). Activity data (area burnt) is based on country-level estimates. Values used for  $M_B$  and  $C_f$  are derived by taking into account estimates of the mass and the amount consumed of unproductive forest, productive forest, dead wood, and humus. The quantification of national estimates for biomass burned and carbon released is based on expert judgment.

Estimated emissions are shown in Table 6.42.

**Table 6.42 Estimates of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions (kt CO<sub>2</sub> equivalents) from forest fires from 1990 to 2021.**

| Year | CO <sub>2</sub> (kt) | CH <sub>4</sub> (kt CO <sub>2</sub> eq) | N <sub>2</sub> O (kt CO <sub>2</sub> eq) | SUM (kt CO <sub>2</sub> eq) |
|------|----------------------|-----------------------------------------|------------------------------------------|-----------------------------|
| 1990 | 9.7500               | 0.8178                                  | 0.4282                                   | 10.9959                     |
| 1991 | 16.3984              | 1.3754                                  | 0.7201                                   | 18.4940                     |
| 1992 | 15.0470              | 1.2621                                  | 0.6608                                   | 16.9699                     |
| 1993 | 2.7862               | 0.2337                                  | 0.1223                                   | 3.1422                      |
| 1994 | 3.1657               | 0.2655                                  | 0.1390                                   | 3.5702                      |
| 1995 | 1.2542               | 0.1052                                  | 0.0551                                   | 1.4145                      |
| 1996 | 8.7727               | 0.7358                                  | 0.3852                                   | 9.8937                      |
| 1997 | 9.4169               | 0.7898                                  | 0.4135                                   | 10.6202                     |
| 1998 | 3.4539               | 0.2897                                  | 0.1517                                   | 3.8953                      |

|      |         |        |        |         |
|------|---------|--------|--------|---------|
| 1999 | 0.7134  | 0.0598 | 0.0313 | 0.8045  |
| 2000 | 1.4907  | 0.1250 | 0.0655 | 1.6812  |
| 2001 | 0.6067  | 0.0509 | 0.0266 | 0.6842  |
| 2002 | 2.8934  | 0.2427 | 0.1271 | 3.2632  |
| 2003 | 6.0855  | 0.5104 | 0.2672 | 6.8631  |
| 2004 | 1.2223  | 0.1025 | 0.0537 | 1.3785  |
| 2005 | 3.5751  | 0.2999 | 0.1570 | 4.0320  |
| 2006 | 32.4306 | 2.7201 | 1.4241 | 36.5749 |
| 2007 | 2.5324  | 0.2124 | 0.1112 | 2.8560  |
| 2008 | 51.5021 | 4.3197 | 2.2616 | 58.0835 |
| 2009 | 8.8988  | 0.7464 | 0.3908 | 10.0359 |
| 2010 | 14.6181 | 1.2261 | 0.6419 | 16.4861 |
| 2011 | 1.9400  | 0.1627 | 0.0852 | 2.1879  |
| 2012 | 0.7676  | 0.0644 | 0.0337 | 0.8657  |
| 2013 | 0.5320  | 0.0446 | 0.0234 | 0.6000  |
| 2014 | 5.9401  | 0.4982 | 0.2608 | 6.6992  |
| 2015 | 0.8665  | 0.0727 | 0.0380 | 0.9772  |
| 2016 | 4.3525  | 0.3651 | 0.1911 | 4.9088  |
| 2017 | 3.5030  | 0.2938 | 0.1538 | 3.9507  |
| 2018 | 18.7240 | 1.5705 | 0.8222 | 21.1168 |
| 2019 | 14.0085 | 1.1750 | 0.6152 | 15.7986 |
| 2020 | 3.2546  | 0.2730 | 0.1429 | 3.6705  |
| 2021 | 7.6344  | 0.6403 | 0.3353 | 8.6100  |

#### 6.15.1.1.2 Activity data

Data on burned areas due to wild forest fires are available from the Norwegian Directorate for Civil Protection (DSB) for 1993–2021. Data are available for the number of fires and the area of productive and unproductive forests that burned. There were only data available for the number of fires between 1990 and 1992, and these data were used to estimate the area burned based on the ratio for subsequent years. This method may be very inaccurate because the size of fires is very variable. The number of fires was higher in 1990 – 1992 than later, and it has been assumed that the area burned was proportionally higher (Rypdal et al. 2005).

Standing volumes for unproductive and productive forests were based on average numbers and accounted for 23 and 109 m<sup>3</sup> ha<sup>-1</sup>, respectively (Granhus et al. 2012). In biomass, this equals 12 and 55 t ha<sup>-1</sup>, respectively. The IPCC (2003) estimate that 50% of the biomass is carbon.

In addition to the lack of data on the tree biomass, there is no exact data on the amount of biomass burned per area. Normally, only the needles/leaves, parts of the humus, and smaller branches would burn. The mass of trees burned constitutes 25% of the biomass, which is consistent with IPCC (2003). It is also likely that about 1 m<sup>3</sup> dead wood per ha will be affected by the fire due to its dryness. It is not easy to assess how much of the humus is burned, which depends on the forest type. There is about 7 500 kg of humus per ha, and we assume that 10% is burned. This percentage, however, is very dependent on the vegetation type. The CO<sub>2</sub> estimates provided in Table 6.42 are for comparison only and to enable estimation of N<sub>2</sub>O and CH<sub>4</sub> emissions, and thus, not used in the reported CO<sub>2</sub> emissions.

**Table 6.43 Information on forest fires in Norway for 1990–2021 and estimated CO<sub>2</sub> emissions**

| Year | Number of fires | Unproductive forest (ha) | Productive forest (ha) | Area burned (ha) |
|------|-----------------|--------------------------|------------------------|------------------|
| 1990 | 578             | 679.6                    | 256.4                  | 936.0            |
| 1991 | 972             | 1142.9                   | 431.3                  | 1574.2           |
| 1992 | 892             | 1048.9                   | 395.7                  | 1444.6           |
| 1993 | 253             | 135.5                    | 88.3                   | 223.8            |
| 1994 | 471             | 123.6                    | 108.1                  | 231.7            |
| 1995 | 181             | 77.6                     | 35.5                   | 113.1            |
| 1996 | 246             | 169.7                    | 343.8                  | 513.5            |
| 1997 | 533             | 605.8                    | 260.6                  | 866.4            |
| 1998 | 99              | 164.7                    | 110.3                  | 275.0            |
| 1999 | 148             | 73.4                     | 12.7                   | 86.1             |
| 2000 | 99              | 142.6                    | 29.3                   | 171.9            |
| 2001 | 117             | 84.3                     | 5.2                    | 89.5             |
| 2002 | 213             | 124.7                    | 95.8                   | 220.5            |
| 2003 | 198             | 905.6                    | 36.8                   | 942.4            |
| 2004 | 119             | 84.6                     | 32.3                   | 116.9            |
| 2005 | 122             | 252.4                    | 93.2                   | 345.6            |
| 2006 | 205             | 3222.2                   | 606.7                  | 3828.9           |
| 2007 | 65              | 22.2                     | 106.1                  | 128.3            |
| 2008 | 171             | 1210.2                   | 1963.6                 | 3173.8           |
| 2009 | 109             | 1257.9                   | 70.8                   | 1328.7           |
| 2010 | 62              | 165.9                    | 602.8                  | 768.7            |
| 2011 | 49              | 47.8                     | 73.4                   | 121.2            |
| 2012 | 24              | 35.1                     | 24.9                   | 60.0             |



|      |     |        |       |        |
|------|-----|--------|-------|--------|
| 2013 | 40  | 30.8   | 15.6  | 46.4   |
| 2014 | 133 | 681.7  | 87.7  | 769.4  |
| 2015 | 40  | 141.6  | 2.0   | 143.6  |
| 2016 | 248 | 434.9  | 80.8  | 515.7  |
| 2017 | 191 | 368.1  | 60.4  | 428.5  |
| 2018 | 771 | 1572.0 | 424.1 | 1996.1 |
| 2019 | 200 | 2231.2 | 47.2  | 2278.4 |
| 2020 | 291 | 294.8  | 68.2  | 363.0  |
| 2021 | 263 | 425    | 228.2 | 653.2  |

Source: Norwegian Directorate for Civil Protection (DSB) \*Area estimated in Rypdal et al. (2005).

#### 6.15.1.1.3 Emission factors

The IPCC (2006) emission ratios of 4.70 g/kg and 0.26 g/kg dry matter burnt are used for methane and nitrous oxide, respectively.

#### 6.15.1.2 Uncertainties

The total uncertainty for wildfires was estimated at 75% based on the default uncertainty for the non-CO<sub>2</sub> emission factor of 70% IPCC (2003) and expert judgment on the activity data.

#### 6.15.1.3 Recalculations

This source was recalculated due to updated data on estimated forest areas affected by wildfires.

See chapter 10.2.4 for details.

#### 6.15.1.4 Planned improvements

There are no planned improvements.

#### 6.15.1.5 Completeness

Reporting of emissions from source 4(V) Biomass burning is complete.

Emissions of non-CO<sub>2</sub> for controlled forest fires and grassland wildfires are reported as NE. An assessment was made of the likely level of emission from these sources. They all qualify as non-significant; see below. For the aggregate criteria (threshold: for all non-significant (NE) estimates a relative 0.1% of non-LULUCF national emissions, see section 6.1.5).

##### 6.15.1.5.1 Non-significant emissions: Controlled forest fires, CH<sub>4</sub>, N<sub>2</sub>O

There are no national statistics describing the extent of controlled forest fires. We used an estimate of 7 controlled fires annually with a size of 5 ha each based on an expert judgement (Reidun Mo, personal communication, The Norwegian Directorate for Civil

Protection “Direktoratet for samfunnssikkerhet og beredskap”, DSB). The Tier 1 estimation method, used for non-CO<sub>2</sub> emissions from forest wildfires, is also used to estimate the likely level of emissions for controlled forest fires (IPCC 2006 Guidelines, Vol. 4, Equation 2.27).

The likely level of emissions of CH<sub>4</sub> is 0.032 kt CO<sub>2</sub> eq yr<sup>-1</sup>, and for N<sub>2</sub>O, it is 0.017 kt CO<sub>2</sub> eq yr<sup>-1</sup>. To evaluate if these emissions qualify as “non-significant”, it was related to the Norwegian emissions from all sectors except the LULUCF sector: range 46954-56394 kt CO<sub>2</sub> eq yr<sup>-1</sup> for the years 1990 – 2019 (NIR 2023, CRF table Summary 2). For both CH<sub>4</sub> and N<sub>2</sub>O, the likely level of emissions makes up less than the relative threshold of 0.05% of national non-LULUCF emissions and is lower than the absolute threshold of 500 kt CO<sub>2</sub> eq yr<sup>-1</sup>. We conclude that these emissions qualify as being non-significant.

#### 6.15.1.5.2 Non-significant emissions: Grassland wildfires, CH<sub>4</sub>, N<sub>2</sub>O

The Norwegian Directorate for Civil Protection (Norwegian abbreviation DSB) is the authority holding the statistics on landscape fires in Norway. The area definitions in these data are not consistent with those used in the GHG inventory. The area statistics for “grasslands” include settlements (for example, gardens) and cropped land. Area information was available from 2016; the annual burned area ranged from 374 to 3068 ha. For fires recorded to have an extent less than 0.1 ha, an area of 0.09 ha was assumed. A Tier 1 estimation method is used for non-CO<sub>2</sub> emissions (IPCC 2006 Guidelines, Vol. 4, Equation 2.27) with the following input values:

- A = sum of area (ha) in each year,
- $M_B \cdot C_f = 11.5 \text{ tonnes ha}^{-1}$  (shrublands vegetation type, subcategory *Calluna* heath (IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.4).
- $G_{ef} \text{ CH}_4 = 4.7 \text{ g kg}^{-1}$ ,  $G_{ef} \text{ N}_2\text{O} = 0.26 \text{ g kg}^{-1}$  (IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.5 “Extra tropical forest” ).

CO<sub>2</sub> equivalents of CH<sub>4</sub> and N<sub>2</sub>O were calculated from Equation 2.27, where the CH<sub>4</sub>-CO<sub>2</sub> eq =  $L_{fire} \cdot 28$  or N<sub>2</sub>O-CO<sub>2</sub> eq =  $L_{fire} \cdot 265$ .

The likely level of emissions of CH<sub>4</sub> is 2.2 kt CO<sub>2</sub> eq yr<sup>-1</sup>, and for N<sub>2</sub>O, it is 1.1 kt CO<sub>2</sub> eq yr<sup>-1</sup>, expressed as the mean for the years 2016-2019. For individual years, emissions of CH<sub>4</sub> range from 0.8 to 4.6 kt CO<sub>2</sub> eq yr<sup>-1</sup>; for N<sub>2</sub>O, they range from 0.4 to 2.4 kt CO<sub>2</sub> eq yr<sup>-1</sup>.

To evaluate if these emissions qualify as “non-significant”, they were related to the Norwegian emissions from all sectors except the LULUCF sector, as given above. For both CH<sub>4</sub> and N<sub>2</sub>O, the likely level of emissions makes up less than the relative threshold of 0.05% of national non-LULUCF emissions and is lower than the absolute threshold of 500 kt

CO<sub>2</sub> eq yr<sup>-1</sup>. For the year 2019 (largest known burned area), both CH<sub>4</sub> and N<sub>2</sub>O emissions were estimated to be 0.01% of national non-LULUCF emissions. Based on this, we conclude that emissions from grassland wildfires qualify as being non-significant.

## 7. Waste (CRF sector 5)

### 7.1 Overview

This sector includes emissions from landfills (CRF 5A), Biological treatment of solid waste (CRF 5B), Incineration and open burning of waste (CRF 5C), and Wastewater treatment and discharge (CRF 5D). Waste incineration from plants with energy utilization is accounted for under Energy industries (CRF 1A1). Waste incineration included in CRF 5C are emissions of greenhouse gases other than CO<sub>2</sub> from methane flared at landfills, and emissions from combustion of hospital waste in hospital incinerators.

The emissions of greenhouse gases from the waste sector decreased by 45.9 % (1.2 million tonnes CO<sub>2</sub> equivalents) from 1990 to 2021. The reductions were mainly due to decreased CH<sub>4</sub> emissions from landfills. Indeed, they decreased by 60.0 % from 1990 to 2021, corresponding to 1.4 million tonnes CO<sub>2</sub> equivalents. Emissions from wastewater treatment decreased by 0.07 million tonnes CO<sub>2</sub> equivalents during the same period. Emissions from waste incineration without energy utilization and biological treatment of waste increased their emissions by 0.2 and 0.07 million tonnes CO<sub>2</sub> equivalents, respectively.

Solid waste disposal on land (i.e., in landfills) is the main emission category within the waste sector, accounting for, in 2021, 63.9 % of the sector's total emissions. Wastewater handling in domestic and industrial sectors account for 16.3 and 2.4 % of the sectors emission. Biological treatment of waste accounts for 4.9 % of emissions from the waste sector and waste incineration, without energy recovery, accounts for 12.4 %.

The waste sector accounted for 2.9 % of the total GHG emissions in Norway in 2021. [Table 7.1](#) presents the key categories included in the Waste sector.

**Table 7.1 Key categories in level or trend in the Waste sector.**

| IPCC | Source category                             | Gas                                | Key category according to approach | Method |
|------|---------------------------------------------|------------------------------------|------------------------------------|--------|
| 5A1  | Managed Waste Disposal on Land              | CH <sub>4</sub>                    | 1                                  | Tier 2 |
| 5B   | Biological treatment of Solid Waste         | CH <sub>4</sub> , N <sub>2</sub> O | 2                                  | Tier 1 |
| 5D1  | Domestic wastewater treatment and discharge | CH <sub>4</sub> , N <sub>2</sub> O | 2                                  | Tier 1 |
| 5D2  | Industrial wastewater                       | N <sub>2</sub> O                   | 2                                  | Tier 1 |

Source: Statistics Norway/Norwegian Environment Agency

## 7.2 Managed Waste Disposal on Land – 5A1

### 7.2.1 Anaerobic managed waste disposal sites, 5A1a (Key category for CH<sub>4</sub>)

#### 7.2.1.1 Description

CH<sub>4</sub> and non-fossil CO<sub>2</sub> are emitted during biological decomposition of waste. This transformation of organic matter takes place in several steps. During the first weeks or months, decomposition is aerobic, and the main decomposition product is CO<sub>2</sub>. When there is no more oxygen left, the decomposition becomes anaerobic, and methane emissions start to increase. After a year or so, CH<sub>4</sub> emissions reach a peak, after that the emissions will decrease over some decades (NCASI 2004; SFT 1999a).

The emissions of methane from landfills have decreased since 1990 and specifically after 1998 due to reduction of the amount of degradable waste disposed at disposal sites. This emissions reduction is the result of several policies and measures introduced in the waste sector, particularly in the 1990s. With few exceptions, notably the mixed waste from households in municipalities with a source separation of food waste, it was then prohibited to dispose easy degradable organic waste, sewage sludge included, at landfills in Norway.

From 1999 to 2014, a tax was introduced on waste delivered to final disposal sites. In 2014, this tax was 294 NOK per tonne waste. From July 1<sup>st</sup>, 2009, it was prohibited to deposit biodegradable waste to landfills. This results in further reduction of methane emissions. In addition to the policies and measures described above, landfills receiving biodegradable waste (waste containing degradable organic carbon (DOC)) are required to collect and treat landfill gas. In 2021, 65 landfills, which had installed a landfill gas extraction system, reported extraction of gas. 5 093 tonnes of methane were recovered representing a 42 per cent decrease compared to 2020. Methane extraction increased until 1999, and then underwent fluctuations until 2008. The fluctuations were due to instability in the pipeline systems. Due to needs for maintenance of the pipeline system, methane extraction was reduced.

Since 2008, extraction has had a decreasing trend. This can be explained by the increased amounts of waste recycled. The total amount of waste generated has increased by almost 63 % from 1995 to 2021, but due to the increase in material recycling and energy utilization, the amount disposed at landfills has dropped substantially since 2008. As a consequence of the prohibition against depositing of biodegradable waste of July 1<sup>st</sup>, 2009, there has been a strong decrease in waste depositing.

Since building the necessary treatment capacity would take time, temporary exemptions were granted in certain cases during a transitional period. Many permits for disposal of biodegradable waste had been given for one year extra, some extended out 2010, and a few within 2011. The transitional period ended on December 31<sup>st</sup> 2012.

In 2021, methane emissions from managed waste disposal sites were 0.9 million tonnes CO<sub>2</sub> equivalents.

According to the approach 1 key category analysis emissions of CH<sub>4</sub> from Managed Waste Disposal sites. Anaerobic (CRF 5A1a) is a key category in level and trend assessment (1990-2021).

It should be noted that the IEF for CH<sub>4</sub> varies mainly due to the reduction in the amount of waste deposited and due to variation of the amount of extracted CH<sub>4</sub> from the landfills.

There are no known semi anaerobic disposal sites in Norway, according to expert judgment (Skullerud, Pers. Comm)<sup>38</sup>, only managed anaerobe disposal sites.

Figure 7-1 shows the relative change (Index 1995=100%) in methane emissions from landfills, extraction of methane, solid waste disposed at landfills and total amount of waste generated in Norway.

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<sup>38</sup> Håkon Skullerud 2014: Personal communication by telephone. Statistics Norway

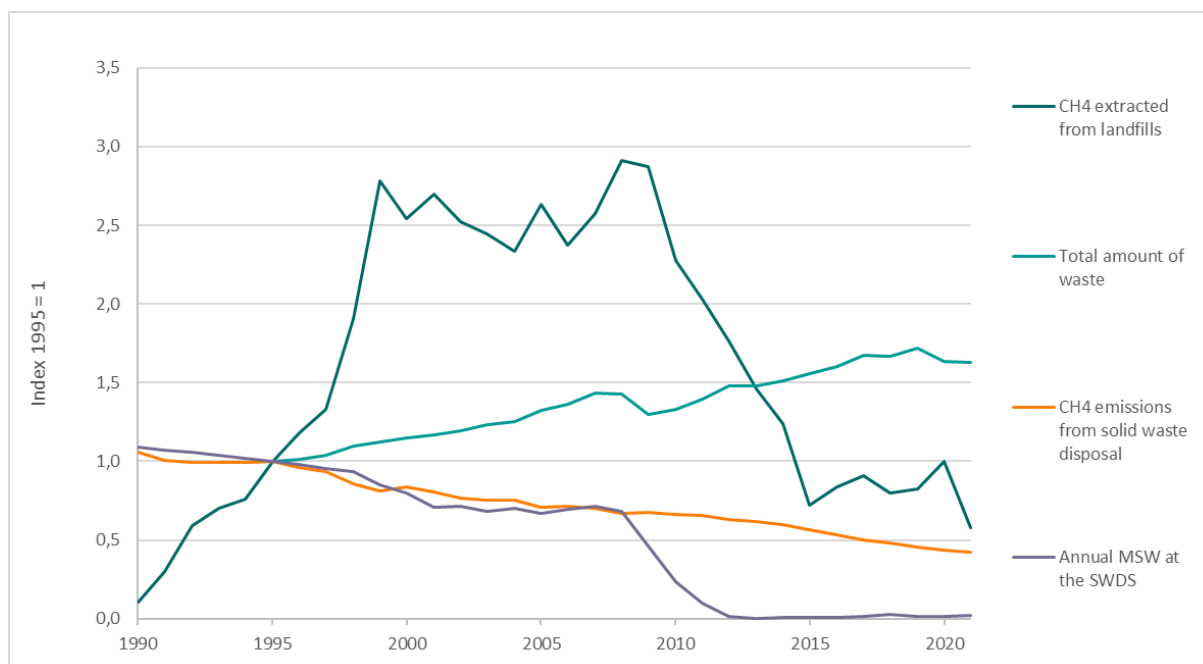


Figure 7-1 Relative change in methane emissions from solid waste disposal, annual MSW at the SWDS, methane extracted from landfills and total amount of waste generated in Norway. 1990-2021 Index 1995 = 1. Source: Statistics Norway/Norwegian Environment Agency

### 7.2.1.2 Methodological issues

The model presented in the IPCC 2006 Guidelines has been used.

This model starts with the calculation of the amount of decomposing  $DDOC_m$  (mass of decomposable organic carbon = the part of DOC (degradable organic carbon) that will decompose (degrade) under anaerobic conditions) contained in the material being landfilled.

As this is a first order reaction, the amount of product formed will always be proportional to the amount of reactant. This means that it is of no concern to the process when the  $DDOC_m$  came into the landfill. As far as we know the amount of  $DDOC_m$  in the landfill at the start of each year, all years can be considered individually in the calculations. This simplifies the model.

With the start of the reaction set to be January 1<sup>st</sup> the year following the landfilling, the “motor” of the new calculating model has been made from these two very simple equations:

$$(7.1) \quad DDOC_{mdiss} = (DDOC_{ma(ly)} + DDOC_{md}) \times (1 - e^{-k})$$

$$(7.2) \quad DDOC_{ma} = (DDOC_{ma(ly)} + DDOC_{md}) \times e^{-k}$$

Equation (7.1) calculates DDOC<sub>mass</sub> decomposing (DDOC<sub>mdiss</sub>) as the sum of the not decomposed DDOC mass accumulated from the previous years (DDOC<sub>ma(ly)</sub>), and the DDOC mass landfilled during the previous year (DDOC<sub>md</sub>).

Equation (7.2) calculates the DDOC mass accumulated as not decomposed (DDOC<sub>ma</sub>), which is then used as (DDOC<sub>ma(ly)</sub>) for the following year's calculations using equation (7.1).

The mass of decomposable organic carbon landfilled (DDOC<sub>md</sub>) is estimated using equation (7.3).

$$(7.3) \quad DDOC_{md} = W \times MCF \times DOC \times DOC_f$$

The amount of decomposed DDOC<sub>m</sub> being estimated, CH<sub>4</sub> produced, and CH<sub>4</sub> emitted are estimated using the equations stated below ((7.4)-(7.9)).

If the reaction of decomposition is set to start during the year of landfilling and not on January 1<sup>st</sup> of the following year, equations (7.1) and (7.2) need to be adjusted.

Equation (7.1) must be replaced by equations (7.4) and (7.5).

$$(7.4) \quad DDOC_{mdi} = DDOC_{md} \times \left(1 - e^{-k \times \left(\frac{13-M}{12}\right)}\right)$$

$$(7.5) \quad DDOC_{mdiss} = DDOC_{ma(ly)} \times (1 - e^{-k}) + DDOC_{mdi}$$

Equation (7.2) must be replaced by equations (7.6) and (7.7).

$$(7.6) \quad DDOC_{ml} = DDOC_{md} \times e^{-k \times \left(\frac{13-M}{12}\right)}$$

$$(7.7) \quad DDOC_{ma} = DDOC_{ma(ly)} \times e^{-k} + DDOC_{ml}$$

The amount of methane produced from decomposition of DDOC is estimated using equation (7.8).

$$(7.8) \quad CH_{4prod} = DDOC_{mdiss} \times F \times 16/12$$



Methane emissions are estimated from the amount of methane produced and the amount of methane recovered. Equation (7.9) details the calculations.

$$(7.9) \quad CH_4 \text{ emitted in year } T = \left( \sum CH_4 \text{ prod } (T) - R(T) \right) \times (1 - OX)$$

Where, in equations (7.1)-(7.9):

|                        |                                                                                        |
|------------------------|----------------------------------------------------------------------------------------|
| W                      | : amount landfilled                                                                    |
| MCF                    | : Methane Correction Factor                                                            |
| M                      | : Month number for reaction start. (January 1, year after landfilling, M=13)           |
| DOC                    | : Degradable Organic Carbon                                                            |
| DOC <sub>f</sub>       | : Fraction of DOC decomposing, anaerobic conditions                                    |
| DDOC <sub>m</sub>      | : Mass of Decomposable Organic Carbon, anaerobic conditions                            |
| DDOC <sub>md</sub>     | : DDOC mass landfilled                                                                 |
| DDOC <sub>ml</sub>     | : DDOC mass left not decomposed from DDOC <sub>m</sub> landfilled, year of landfilling |
| DDOC <sub>ma</sub>     | : DDOC mass left not decomposed at end of year                                         |
| DDOC <sub>ma(ly)</sub> | : DDOC mass accumulated from last year                                                 |
| DDOC <sub>mdi</sub>    | : DDOC mass decomposed from DDOC <sub>m</sub> landfilled, year of landfilling          |
| DDOC <sub>mdiss</sub>  | : DDOC mass decomposed in calculation year                                             |
| CH <sub>4</sub> prod   | : CH <sub>4</sub> produced                                                             |
| F                      | : Fraction of CH <sub>4</sub> by volume in generated landfill gas                      |
| 16/12                  | : Conversion factor from C to CH <sub>4</sub>                                          |
| R(T)                   | : Recovered CH <sub>4</sub> in year of calculation                                     |
| OX                     | : Oxidation factor (fraction).                                                         |

### 7.2.1.3 Activity data

The methane is formed by decomposition of biological waste in landfills. The decomposition time varies from material to material. Easily degradable waste (food, etc.) has shortest decomposition time, while wood waste has the longest decomposition time. Other materials do not emit methane at all, either because they are inorganic (metal, glass, etc.) or because they break down extremely slowly (plastic). It is therefore of vital importance for the calculations that the waste quantities used as input to the model are correct, both total quantity and the distribution by material.

Data over the amount of different waste materials is taken from Statistics Norway's waste accounts. The waste accounts consist of data from several sources, such as special surveys, register data and statistics, indirect data sources such as production statistics, foreign trade

statistics and different factors combined with activity data. Data from all these sources are combined in the waste accounts, which give an overview of waste quantities in Norway, divided into type of product, material, industry and method of treatment. Waste incineration in the waste accounts includes export and is thus not comparable with the emission inventory as a substantial amount is exported to Sweden for incineration.

From 2012 onwards, data for the categories food waste, plastics, wood and paper are taken directly from the waste accounts. The amount of sludge deposited are taken from statistics on discharges and treatment of municipal wastewater. In addition, there is a category "other" in the waste accounts, of which content is not known. Due to the prohibition to deposit biodegradable waste to landfills it is assumed that no methane is formed from these materials.

Historic data up until 2011 have been estimated from the former waste category basis to a waste material basis. The amount of each material type deposited is estimated based on surveys and sorting analyses. The model is based on types of waste materials for instance food waste (incl. garden waste), paper, wood and textiles. All sources of waste, MSW, industrial, commercial, construction and demolition waste are accounted for in these annual surveys.

To ensure that Norway does not underestimate the emissions, a project was carried out in 2018/2019 to investigate the type of waste generated from the construction industry. The project confirmed that waste from the construction industry mainly consists of slightly polluted stone and masses, concrete, bricks, gypsum waste and insulation materials, as well as some waste containing glass, plastics, and wood. The waste is mainly burned, as part of mixed waste, and energy recovered. The construction and demolition waste that is likely to end up in landfill contain only minor amounts of organic waste.

#### Municipal landfills

Historical data for years before 1973 on municipal solid waste deposited are based upon:

- New statistics on municipal waste, divided into household waste and industrial waste (1974 to 1997),
- Estimates based on population,
- Assumption that less people were connected to public waste management during the forties and fifties.

Since 1974, the amount of municipal waste is based upon questionnaires and linear interpolations. Surveys were held in 1974, 1980 and 1985. The amount of waste going to

landfills is allocated to material based on sorting analyses. For the period 1995-2011 the amounts of waste are taken from the waste accounts, with three adaptations:

- Wood content in sludge deposited at industrial sites is added to the amount of deposited wood from the waste accounts,
- Textiles are supposed to consist of 50 % plastic (SFT 2005b). The plastic fraction of deposited textiles is therefore subtracted from the amounts of deposited textiles and added to deposited plastic,
- The material category "Other materials" is assumed to contain degradable organic matter with an average half-life. This degradable share is added to the amount of paper. The amount is estimated by  $0.2 * \text{landfilled 'other materials' from manufacturing} + 0.5 * \text{'other combustible' in landfilled mixed waste from all sectors}$ .

Contaminated soils are assumed not to develop methane in landfills. The same applies to waste used as cover material, due to excess oxygen availability.

No bio-degradable hazardous waste is landfilled in Norway.

No organic waste is imported for landfilling, as it is prohibited.

Due to lack of data, linear interpolation of the amount of waste deposited has been applied to the period 1985-1995.

| Table 7.2 Amounts deposited in municipal SWDS, 1945-2021. 1 000 tonnes. |      |       |      |         |               |          |
|-------------------------------------------------------------------------|------|-------|------|---------|---------------|----------|
| Year                                                                    | Food | Paper | Wood | Textile | Sewage sludge | Plastics |
| 1945                                                                    | 75   | 148   | 120  | 3       | 7             | 11       |
| 1950                                                                    | 116  | 228   | 171  | 4       | 10            | 17       |
| 1955                                                                    | 131  | 256   | 207  | 5       | 11            | 19       |
| 1960                                                                    | 171  | 335   | 258  | 6       | 14            | 25       |
| 1965                                                                    | 258  | 422   | 270  | 8       | 18            | 50       |
| 1970                                                                    | 279  | 463   | 307  | 9       | 20            | 54       |
| 1975                                                                    | 305  | 513   | 318  | 10      | 22            | 59       |
| 1980                                                                    | 343  | 584   | 300  | 11      | 23            | 66       |
| 1985                                                                    | 357  | 635   | 280  | 11      | 24            | 68       |
| 1990                                                                    | 342  | 461   | 280  | 22      | 21            | 144      |
| 1995                                                                    | 327  | 286   | 279  | 33      | 17            | 219      |
| 2000                                                                    | 253  | 249   | 194  | 29      | 13            | 189      |
| 2005                                                                    | 218  | 195   | 169  | 26      | 4             | 164      |
| 2010                                                                    | 71   | 69    | 54   | 9       | 2             | 65       |
| 2011                                                                    | 29   | 33    | 23   | 3       | 2             | 28       |
| 2012                                                                    | 0    | 1     | 8    | 0       | 1             | 3        |
| 2013                                                                    | 0    | 1     | 0    | 0       | 2             | 2        |
| 2014                                                                    | 1    | 1     | 0    | 0       | 5             | 2        |
| 2015                                                                    | 3    | 2     | 2    | 0       | 3             | 3        |
| 2016                                                                    | 1    | 0     | 5    | 0       | 1             | 3        |
| 2017                                                                    | 1    | 2     | 2    | 0       | 8             | 4        |
| 2018                                                                    | 3    | 3     | 2    | 4       | 2             | 18       |
| 2019                                                                    | 1    | 0     | 0    | 0       | 2             | 12       |
| 2020                                                                    | 1    | 0     | 1    | 0       | 4             | 14       |
| 2021                                                                    | 1    | 0     | 0    | 0       | 8             | 13       |

Source: Statistics Norway/Norwegian Environment Agency

### Industrial disposal sites

Historical data for industrial waste for years before 1970 are estimated by extrapolation using the same trend as for municipal waste. After 1970, literature studies and information from the industrial waste study from the years 1993, 1996, 1999 and 2003 have been used. Linear interpolation is used for the years where data are missing.

Data from each landfill site with methane recovery units are reported by the landfills via an electronic web portal and the Norwegian Environment Agency assembles these data in

their own database. Further, these data are imported into the national model for calculating methane from landfills.

**Table 7.3 Waste amounts deposited in industrial SWDS, 1945- onwards. 1 000 tonnes.**

| Year          | Food  | Paper | Wood    | Textile | Plastics |
|---------------|-------|-------|---------|---------|----------|
| 1945          | 476   | 339   | 74 160  | 756     | 180      |
| 1950          | 735   | 524   | 101 108 | 1 167   | 277      |
| 1955          | 825   | 588   | 128 056 | 1 310   | 311      |
| 1960          | 1 077 | 767   | 155 004 | 1 710   | 406      |
| 1965          | 1 776 | 888   | 181 952 | 1 869   | 888      |
| 1970          | 2 000 | 1 000 | 208 900 | 2 000   | 1 000    |
| 1975          | 2 000 | 1 000 | 208 900 | 2 000   | 1 000    |
| 1980          | 2 000 | 1 000 | 173 872 | 2 000   | 1 000    |
| 1985          | 2 000 | 1 000 | 138 844 | 2 000   | 1 000    |
| 1990          | 2 000 | 1 000 | 103 817 | 2 000   | 1 000    |
| 1995          | 1936  | 899   | 88 800  | 1 957   | 759      |
| 2000          | 0     | 200   | 677     | 0       | 0        |
| 2001          | 0     | 38    | 0       | 0       | 0        |
| 2005- onwards | 0     | 0     | 0       | 0       | 0        |

Source: Statistics Norway/Norwegian Environment Agency

#### 7.2.1.4 Emission factors

All parameters used in the Norwegian model are IPCC defaults values for Northern Europe. Table 7.4 shows some of the variables used in the calculations of methane emissions from solid waste disposals both municipal and industrial.

**Table 7.4 Variables used in the calculations of methane from landfills.**

| Variables                                    | Type of waste |       |       |          |               |
|----------------------------------------------|---------------|-------|-------|----------|---------------|
|                                              | Food waste    | Paper | Wood  | Textiles | Sewage sludge |
| $t_{1/2}$ (half lifetime) (years)            | 3.7           | 11.6  | 23.1  | 11.6     | 3.7           |
| DOC (Mg/Mg)                                  | 0.150         | 0.400 | 0.430 | 0.24     | 0.05          |
| DOC <sub>f</sub> (Part of DOC decomposing)   | 0.5           | 0.5   | 0.5   | 0.5      | 0.5           |
| Ox. Methane oxidized in top layer            | 0.1           | 0.1   | 0.1   | 0.1      | 0.1           |
| F. Part of methane in generated landfill gas | 0.5           | 0.5   | 0.5   | 0.5      | 0.5           |

Source: IPCC (2006)

In Norway, all SWDS are considered well managed and covering including oxidising material shall apply according to the regulation on SWDS.

#### **7.2.1.5 Uncertainties and time-series consistency**

The amount of different waste materials is considered to be known within  $\pm 20\%$ . The emission factors used are considered to have the uncertainty range  $\pm 30\%$ . More information about the uncertainty estimates for this source is given in Annex II.

The importance of the uncertainties in calculations of methane from landfills will decrease with decreased source contribution and improved IPCC default parameter values, but most likely it will remain among the main uncertainties in the Norwegian GHG inventory.

The methodology Statistics Norway/the Norwegian Environment Agency use to calculate methane emissions from landfills is consistent for the whole time series. The quality of the activity data used in the model has been improved in the last years. This is also the case regarding the data for recovered methane.

In 2014, a major revision of the methodologies of the waste accounts took place. The time series for waste amounts has not been recalculated to take this new information into account. There are several reasons for this, among others that many sources for the statistics do not have numbers for earlier years. Since 2012, publication divides waste into new categories, different from the previous categories. The category "mixed waste" is no longer separated into its different material types. See Statistics Norway's documentation of the waste accounts for more details about the revisions (Statistics Norway Annually-c).

This change in the waste accounts introduces a certain degree of inconsistency in the time series of the activity data used for the calculation of methane emissions from municipal landfills. However, due to the measures described in 7.2.1.1, the amount of biological waste deposited at SWDS is currently very low, and the effect of the alterations in the waste accounts are thus considered to be negligible.

#### **7.2.1.6 Source specific QA/QC and verification**

Internal checks of time series for all emission sources are conducted every year along with the new inventory production.

Internal checks are carried out for time series of waste data, methane recovered at landfill sites and calculated methane emissions from the model. Corrections are made if necessary.

The Norwegian Environment Agency contacts landfill sites to discuss outliers and major changes in the trend of methane recovery. Corrections are made if necessary.

#### **7.2.1.7 Recalculations**

Activity data in the previous year is updated each year for amounts of food, paper, wood, textile and plastic deposited. This is because the activity data in the Norwegian waste accounts is released too late to be included in the inventory.

In the 2023-submission the amounts of recovered landfill gas have been updated in the period of 2017-2020. The impact of the update is a total reduction in emission of 494 tonnes over those four years. The highest reduction was in 2019, where the recovery increased by 524 tonnes, equal to an increase of 8 per cent in recovery compared to the 2022 submission.

There has been a decline in the NMVOC emissions in the whole timeseries due to a change of data source. Previously it was assumed that the NMVOC was in line with the total amount of CH<sub>4</sub> from landfill sites. In the updated calculation the activity data is changed to total amount of CH<sub>4</sub> corrected for the amount recovered. The reason is that the amounts of NMVOC should be in line with the amounts of CH<sub>4</sub> emitted, not the amounts of CH<sub>4</sub> in total. Details on the recalculation are given in chapter 10.

#### **7.2.1.8 Planned improvements**

There are no improvements planned for this sector.

## **7.3 Unmanaged Waste Disposal Sites – 5A2**

In Norway, landfilling of solid waste has been regulated and controlled for some decades, and unmanaged landfills date from before 1970. Furthermore, the methane emissions for all years have been calculated from the total amounts of landfilled materials. Therefore, unmanaged waste disposal sites are not occurring and hence Norway does not separately report emissions from unauthorized/unmanaged SWDSs.

## 7.4 Biological treatment of Solid Waste – 5B (Key category for CH<sub>4</sub>)

### 7.4.1 Composting and Anaerobic digestion of organic waste – 5B1 and 5B2

#### 7.4.1.1 Description

This section covers the biological treatment of solid waste and wastewater (5B2b).

**Composting** is an aerobic process. A large fraction of the degradable organic carbon (DOC) in the waste material is oxidized into carbon dioxide (CO<sub>2</sub>). CH<sub>4</sub> is also formed during the process, in anaerobic sections of the compost, but is largely oxidized in the aerobic sections of the compost. Composting can also produce emissions of N<sub>2</sub>O.

**Anaerobic digestion of organic waste** expedites the natural decomposition of organic material without oxygen, i.e., biogas production from municipal solid waste and wastewater.

In the Norwegian inventory, emissions from compost production and biogas production without energy recovery are included in this category. CH<sub>4</sub>, N<sub>2</sub>O and CO<sub>2</sub> are emitted during this process. CO<sub>2</sub> emissions from compost production are biogenic.

According to the approach 2 key category analysis emissions of CH<sub>4</sub> and N<sub>2</sub>O from Biological treatment of solid waste (CRF 5B) is key categories in trend assessment (1990-2019).

#### 7.4.1.2 Methodological issues

Emissions from composting of municipal waste have been calculated according to the Tier 1 default methodological guidance available in the guidelines (IPCC 2006).

#### CH<sub>4</sub> emissions from biological treatment

$$(7.10) \quad CH_4 \text{ Emissions} = \sum_i (M_i * EF_i) * 10^{-3}$$

Where:

|                           |                                                                            |
|---------------------------|----------------------------------------------------------------------------|
| CH <sub>4</sub> Emissions | : total CH <sub>4</sub> emissions in inventory year, Gg                    |
| M <sub>i</sub>            | : mass of organic waste treated by biological treatment type <i>i</i> , Gg |
| EF                        | : emission factor for treatment <i>i</i> , g CH <sub>4</sub> /kg waste     |
| i                         | : composting or anaerobic digestion                                        |



In Norway, composting of solid biological waste includes composting of:

- organic waste from households and other sources,
- garden and park waste (GPW),
- sludge,
- home composting of garden and vegetable food waste.

CH<sub>4</sub> emissions from anaerobic digestion at biogas facilities are estimated based on the amount of waste treated at biogas facilities multiplied by the IPCC default emission factor. Norway is currently improving the data quality for both the amount of waste treated in biogas facilities, and the amount of energy produced. When the data is available, Norway will consider using them in the calculation of the emissions.

Composting is performed with simple technology in Norway; this implies that temperature, moisture, and aeration are not consistently controlled or regulated. During composting, a large fraction of the degradable organic carbon (DOC) in the waste material is converted into CO<sub>2</sub>. Anaerobic sections are inevitable and cause emissions of CH<sub>4</sub>. In the same manner, aerobic biological digestion of N leads to emission of N<sub>2</sub>O (IPCC 2006).

#### N<sub>2</sub>O emissions from composting

$$(7.11) \quad N_2O \text{ Emissions} = \sum_i (M_i * EF_i) * 10^{-3}$$

Where:

|                            |                                                                    |
|----------------------------|--------------------------------------------------------------------|
| N <sub>2</sub> O Emissions | : total N <sub>2</sub> O emissions in inventory year, Gg           |
| M <sub>i</sub>             | : mass of organic waste treated by biological treatment type i, Gg |
| EF                         | : emission factor for treatment i, g N <sub>2</sub> O/kg waste     |

Emissions from compost production are considered to be complete; calculations include composting at all nationally registered sites and best available estimated data for home composting.

#### **7.4.1.3 Activity data**

All Norwegian waste treatment plants are obligated to statutory registration and reporting of all waste entering and leaving the plants. All waste streams are weighed, categorized according to a waste type and type of treatment. Data is available for all years since 1995. Activity data for the years since 1995 are collected from Statistics Norway's, waste statistics. Data for 1991 is also available from the waste statistics. For the year 1990, activity data for 1991 have been used, while AD for 1995 is used for 1992 to 1994.

| <b>Table 7.5 Amount of waste biologically treated at composting and biogas facilities, 1990-2021.<br/>Tonnes of waste on wet basis.</b> |            |                                     |                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------|------------|-------------------------------------|------------------------------------|
| Year                                                                                                                                    | Composting | Anaerobic digestion,<br>solid waste | Anaerobic digestion,<br>wastewater |
| 1990                                                                                                                                    | 21 000     | 0                                   | 19 003                             |
| 1995                                                                                                                                    | 57 000     | 0                                   | 317 320                            |
| 2000                                                                                                                                    | 234 000    | 0                                   | 611 214                            |
| 2005                                                                                                                                    | 319 232    | 4 768                               | 780 964                            |
| 2010                                                                                                                                    | 359 384    | 86 616                              | 832 399                            |
| 2011                                                                                                                                    | 296 000    | 105 000                             | 830 807                            |
| 2012                                                                                                                                    | 407 000    | 57 000                              | 834 849                            |
| 2013                                                                                                                                    | 441 000    | 77 000                              | 890 996                            |
| 2014                                                                                                                                    | 328 000    | 80 000                              | 865 158                            |
| 2015                                                                                                                                    | 309 000    | 289 000                             | 918 666                            |
| 2016                                                                                                                                    | 357 000    | 226 000                             | 951 997                            |
| 2017                                                                                                                                    | 273 000    | 194 000                             | 998 116                            |
| 2018                                                                                                                                    | 313 000    | 249 000                             | 1 208 303                          |
| 2019                                                                                                                                    | 213 000    | 196 000                             | 1 106 765                          |
| 2020                                                                                                                                    | 226 000    | 220 000                             | 1 603 385                          |
| 2021                                                                                                                                    | 226 000*   | 220 000*                            | 1 113 825                          |

*\* Figures for the last inventory year have been set equal to the previous year because the waste accounts have not been updated in time for the emission inventory calculations.*

*Source: Statistics Norway*

### Home composting

The last waste category involved in composting is home composting of garden waste and vegetable waste. The activity data for this category is available for the years 2009 to 2012 from Statistics Norway. The amount of organic waste from households composted for the period 1990-2008 is estimated assuming that 3 % of all households composts their garden and vegetable food waste (Lystad 2005). The average value of the period 2009-2012, 2.6 %, has been used for the following period.

| <b>Table 7.6 Number of households with home composting and amount of organic waste composted, 1990-2021. Tonnes.</b> |                                           |                                   |
|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------------------------|
| Year                                                                                                                 | Number of households with home composting | Amount of organic waste composted |
| 1990                                                                                                                 | 52 541                                    | 8 200                             |
| 1995                                                                                                                 | 55 407                                    | 10 234                            |
| 2000                                                                                                                 | 58 273                                    | 12 607                            |
| 2005                                                                                                                 | 60 330                                    | 15 764                            |
| 2010                                                                                                                 | 57 307                                    | 14 310                            |
| 2011                                                                                                                 | 57 479                                    | 13 703                            |
| 2012                                                                                                                 | 54 786                                    | 12 852                            |
| 2013                                                                                                                 | 58 848                                    | 14 135                            |
| 2014                                                                                                                 | 59 569                                    | 14 200                            |
| 2015                                                                                                                 | 60 356                                    | 14 390                            |
| 2016                                                                                                                 | 61 193                                    | 14 326                            |
| 2017                                                                                                                 | 61 927                                    | 14 214                            |
| 2018                                                                                                                 | 62 768                                    | 14 127                            |
| 2019                                                                                                                 | 63 549                                    | 14 329                            |
| 2020                                                                                                                 | 64 485                                    | 15 279                            |
| 2021                                                                                                                 | 65 453                                    | 13 517                            |

Source: Statistics Norway

#### 7.4.1.4 Emission factors

Emissions from composting, and anaerobic digestion in biogas facilities, will depend on the composition of waste composted, the amount and type of supporting material used (such as wood chips and peat), the temperature, the moisture content, and the aeration during the process.

Table 7.7 gives the default factors for CH<sub>4</sub> and N<sub>2</sub>O emissions from biological treatment for the Tier 1 method used in the Norwegian inventory (IPCC 2006). The CO<sub>2</sub> produced and emitted during composting is short-cycled C and is therefore regarded as CO<sub>2</sub> neutral (Boldrin et al. 2009).

| Table 7.7 Composting emission factors. kg/tonnes. |            |                                          |                 |
|---------------------------------------------------|------------|------------------------------------------|-----------------|
|                                                   | Composting | Anaerobic digestion at biogas facilities | Home composting |
| <b>CH<sub>4</sub></b>                             | 4          | 0.8*                                     | 4               |
| <b>N<sub>2</sub>O</b>                             | 0.24       | NO                                       | 0.24            |

\*Amount of waste on a wet basis

Source: IPCC (2006)

#### 7.4.1.5 Uncertainties and time-series consistency

The amount of waste biological treated at composting and biogas facilities is considered to be known within  $\pm 20$  %. The amount of waste composted at home is considered to be known within  $\pm 100$  %. The emission factors used are considered to have the uncertainty range  $\pm 100$  %. More information about the uncertainty estimates for this source is given in Appendix D.

The methodology Statistics Norway/the Norwegian Environment Agency use to calculate emissions from biological treatment of solid waste is consistent for the whole time series.

#### 7.4.1.6 Source specific QA/QC and verification

Internal checks of time series for all emission sources are conducted every year along with the new inventory production.

Internal checks are carried out for time series of waste data and calculated methane emissions. Corrections are made if necessary.

#### 7.4.1.7 Recalculations

##### Composting facilities

Activity data for the previous year, 2020, have been updated because the Norwegian waste accounts has not released updated figures in time for the emission inventory calculations. The updated waste amounts led to an increase in CH<sub>4</sub> and N<sub>2</sub>O emissions of 6.1 per cent in 2020 compared to the 2022 submission.

##### Homecomposting

The amounts of organic waste composted were updated for 2019 and 2020 due to new information. This led to an increase of 2.8 per cent in 2020 for emissions of CH<sub>4</sub> and only a minor decline in 2019.

There was also a correction in the emissions in the period of 1990-2008 due to an error in the calculation. The correction led to a decline in the emission corresponding to 1.1 per cent for the whole period. Details can be found in chapter 10.

Biogas facilities – municipal solid waste

Activity data for the previous year, 2020, have been updated because the Norwegian waste accounts has not released updated figures in time for the emission inventory calculations. The updated waste amounts led to an increase in the CH<sub>4</sub> emissions of 12.2 per cent in 2020 compared to the 2022 submission.

Biogas facilities – wastewater

The produced amounts of biogas have been updated in 2018 and 2019 due to new information from one facility in the 2023 submission. The updated figures led to a decrease in the CH<sub>4</sub> emissions by 1.4 per cent in 2018 and 3.7 percent in 2019.

**7.4.1.8 Planned improvements**

Norway has collected plant specific activity data and will investigate availability of technology specific emission factors to implement a higher Tier methodology as recommended by the ERT.

## 7.5 Waste incineration – 5C

**7.5.1 Description**

Emissions from waste incineration in district heating plants are reported under energy industries (CRF 1A1a), as the energy is utilized, and therefore described in Chapter 3. In 2020, there were 18 waste incineration plants where household waste was incinerated. In addition, some incineration plants burn waste other than household waste, mainly wooden waste, paper, pasteboard, and cardboard. These emissions are reported and described under energy (CRF 1A1a). Waste, other than household waste, is also used as energy source in some manufacturing industries. These emissions are reported and described in the relevant subsectors under energy in manufacturing industries (CRF 1A2). Flaring offshore and in refineries are included under fugitive emissions (CRF 1B2c). Flaring in chemical industry is included under chemical process emissions (CRF 2B8a). In this chapter, the focus will be on waste reported in IPCC sector 5C. This includes emissions from flaring of landfill gas at waste treatment plants, flaring of biogas in industry, incineration of municipal waste without energy recovery and hospital waste. Incineration of municipal waste without energy include both the facilities without energy recovery and the share of waste that is burned without utilization of the energy at district heating plants.

In Norway, the open burning of private yard waste is under different restrictions according to the respective municipality. These restrictions include what can be burned, but also the quantity, how, when and where it can be burned. In some municipalities, a complete ban is

imposed. There is no registration of private waste burning and the activity data on this subject are difficult to estimate. Citizens are generally encouraged to compost their yard waste or to dispose of it through one of the many waste disposal/recycling sites. Emissions from open burning of waste are considered to be insignificant and have therefore not been included in the inventory.

### 7.5.2 Methodological issues

#### Landfill gas

Emissions from flaring of landfill gas by landfills are estimated. However, CO<sub>2</sub> emissions from flaring of landfills are not included in the inventory, as these are considered as being of biogenic origin. Emissions have been estimated by multiplying the amount of gas flared with the emission factors shown in [Table 7.10](#).

#### Municipal waste incineration – CO<sub>2</sub> and CH<sub>4</sub>

Net CO<sub>2</sub> emissions from wood/ biomass burning are not considered in the Norwegian inventory, because the amount of CO<sub>2</sub> released during burning is the same as that absorbed by the plant during growth. Carbon emitted in compounds other than CO<sub>2</sub>, e.g., as CO, CH<sub>4</sub> and NMVOC is also included in the CO<sub>2</sub> emission estimates. This double counting of carbon is in accordance with the IPCC guidelines (IPCC 2006).

#### Municipal waste incineration – N<sub>2</sub>O

Emissions of N<sub>2</sub>O are derived from the emissions of NO<sub>x</sub>, which are reported from each plant to the Norwegian Environment Agency. More specifically, an estimated amount of 2.5 % of this NO<sub>x</sub> is subtracted and reported to UNFCCC as N<sub>2</sub>O (SFT 1996). Accordingly, the net NO<sub>x</sub> emissions constitute 97.5 % of the emissions reported by the plants. For some years, emissions of NO<sub>x</sub> have not been reported for a number of plants. In these cases, specific emission factors for the plants have been made, based upon earlier emissions and amounts of waste incinerated. These new factors have been used to estimate the missing figures.

#### Hospital waste

Emissions from combustion of hospital waste have been calculated based on an emission factor and the amount hospital waste incinerated. Since 2006, hospital wastes have been incinerated in municipal waste incineration plants and emissions are then reported under energy industries (CRF 1A1a).

### 7.5.3 Activity data

#### Landfill gas

The total amount of landfill gas extracted each year is reported by landfill owners to the Norwegian Environment Agency and to Statistics Norway. The data are based on

measurements of both amount of gas and CH<sub>4</sub> content. Most landfill owners are required to measure continuously, and as a minimum to report: Hours of operation, amount of gas extracted, volume percentage of CH<sub>4</sub>, and amount of CH<sub>4</sub> used for flaring, heat, and electricity. The landfill operator reports the percentage of methane, along with the total amount of landfill gas (volume) to the Norwegian Environment Agency. The amount of recovered methane is then calculated.

Statistics Norway subtracts the amount utilized for district heating and thermal power, which is given by the energy statistics in Statistics Norway. Information on the amount flared is given by the Norwegian Environment Agency and by surveys in Statistics Norway. Emissions from the amount of landfill gas flared is included under 5C1a, municipal solid waste. Emissions from landfill gas used for district heating and used in other sectors are reported in the relevant subsectors under Energy (CRF 1A1 and 1A4).

**Table 7.8 Amount of landfill gas flared or used for energy purposes. Tonnes CH<sub>4</sub>.**

| Year | 5C. Flared | 1A1a Public electricity and heat production | 1A4a, Other sectors, commercial/institutional |
|------|------------|---------------------------------------------|-----------------------------------------------|
| 1990 | 879        | 0                                           | 67                                            |
| 1995 | 6 098      | 208                                         | 2 533                                         |
| 2000 | 15 471     | 3 654                                       | 3 350                                         |
| 2005 | 10 331     | 187                                         | 12 777                                        |
| 2010 | 10 079     | 1 393                                       | 8 636                                         |
| 2011 | 8 581      | 1 495                                       | 7 745                                         |
| 2012 | 9 567      | 1 154                                       | 7 312                                         |
| 2013 | 6 097      | 971                                         | 5 837                                         |
| 2014 | 4 850      | 1 742                                       | 4 358                                         |
| 2015 | 4 028      | 902                                         | 1 425                                         |
| 2016 | 3 471      | 2 036                                       | 1 874                                         |
| 2017 | 3 684      | 1 075                                       | 3 262                                         |
| 2018 | 3 702      | 1 010                                       | 2341                                          |
| 2019 | 4 225      | 374                                         | 2140                                          |
| 2020 | 4 467      | 858                                         | 3 511                                         |
| 2021 | 4 824      | 774                                         | 934                                           |

Source: Statistics Norway/ Norwegian Environment Agency

### Natural gas

The amount of natural gas flared by the production of methanol is, as recommended by the ERT, reported under 2B8.

### Hospital waste

The amount of hospital waste was reported to Statistics Norway for the years 1998 and 1999. For the period 1990-1997, the average for 1998 and 1999 has been used. After 1999, as there has been no collection of hospital waste data, and due to the lack of better information, the waste amount of 1999 has been used to calculate the emissions for the subsequent years.

Hospital incinerators have gradually been closed down, mainly due to new emission limit values. Since 2006, no hospital incinerator has been running and hospital waste has been incinerated in incinerators for municipal waste. Therefore, emissions are included under energy (CRF 1A1a).

**Table 7.9 Estimated amount of hospital waste incinerated in hospital incinerators. 1 000 tonnes.**

| Year | Hospital waste incinerated |
|------|----------------------------|
| 1990 | 0.63                       |
| 1995 | 0.48                       |
| 2000 | 0.24                       |
| 2001 | 0.24                       |
| 2002 | 0.14                       |
| 2003 | 0.14                       |
| 2004 | 0.14                       |
| 2005 | 0.14                       |

Source: Statistics Norway

## 7.5.4 Emission factors

Table 7.10 presents the emission factors used for calculating emissions from flaring and hospital waste.

**Table 7.10 Emission factors for flare and hospital waste incineration.**

| Component        | Flare Landfill gas <sup>1</sup> and biogas | Hospital waste |
|------------------|--------------------------------------------|----------------|
|                  | kg/tonnes                                  | Tonnes/tonnes  |
| CO <sub>2</sub>  | 0                                          | 0.3            |
| CH <sub>4</sub>  | 0.37                                       | 0.00023        |
| N <sub>2</sub> O | 0.0015                                     | 0.000035       |

Source: <sup>1</sup>SFT (1996)



### 7.5.5 Uncertainties and time-series consistency

#### Activity data

Uncertainty estimates for greenhouse gases are presented and discussed in Annex II. No new data on the amount of hospital waste has been reported since 1999. The amount of hospital waste incinerated the subsequent years may vary from the data reported in 1999 currently used in the inventory for the period 2000-2005. Uncertainty has been estimated to  $\pm 30\%$ .

#### Emission factors

Uncertainty estimates for greenhouse gases are presented and discussed in Annex II. If the composition of the hospital waste is different from the one, which the emission factors are based on, the calculated emissions will be incorrect. Combustion engineering and processes also influence the emissions. See Annex II.

### 7.5.6 Source specific QA/QC and verification

Landfill gas recovered from sites with recovery is reported to the Norwegian Environment Agency. Each site reporting on the use of the gas, that is, whether the gas is flared or used for energy purposes. The information is also checked against information collected from Statistics Norway regarding production.

Incineration of municipal waste is strongly regulated in Norway. All data concerning the waste incinerated is reported to the Norwegian Environment Agency per incineration plant; each facility has a unique identification code, thereby ensuring good-quality data without double counting.

The sections above secure potential problems regarding cross-sectoral issues and no double counting between waste and energy sectors.

See Section 1.2 for a description of the general QA/QC procedures of the Norwegian emission inventory.

### 7.5.7 Recalculations

There have been adjustments in the activity data in 5C11A in the period of 2010-2020, leading to relatively high percentage changes due to low emissions of N<sub>2</sub>O and CH<sub>4</sub>. Total changes in the emissions for N<sub>2</sub>O and CH<sub>4</sub> were a reduction of 3.9 and 28 tonnes respectively. The total reduction in CO<sub>2</sub> emissions was 99.2 ktonnes.

There has also been a correction of an error in this sector. In the 2022 submission a correction was made in 2012 for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. This correction is also implemented for NMVOC in the present submission, leading to a reduction of 41.5 per cent NMVOC in 2012.

There has been a correction in the reported amounts of flared biogas from one facility in 2019. The correction led to a reduction in the emissions of CH<sub>4</sub> and N<sub>2</sub>O in 5.C1.1.b.

The CO<sub>2</sub> emissions in this sector

An error in the emission factors used in the calculation of CO<sub>2</sub> emissions in 5.C.1.2.a has been corrected from the 2022 submission.

The activity data in 5.C.1.2 have been updated due to a reallocation from 1A1A. This reallocation is made due to a quality check to secure the correct distribution of waste burned with and without energy utilization. The result is an increase in emissions throughout the period 2003-2020. Details are given in chapter 10.

### 7.5.8 Planned improvements

There are no planned improvements in 5C.

## 7.6 Wastewater treatment and discharge – 5D (Key category for CH<sub>4</sub> and N<sub>2</sub>O)

### 7.6.1 Overview

In 2021, wastewater handling accounted for 18.7 % of the emissions in the waste sector. CH<sub>4</sub> and N<sub>2</sub>O emissions from Wastewater handling have been reduced by 21.0 % between 1990 and 2021. Emissions have been relatively stable since 1998.

Wastewater can be a source of methane (CH<sub>4</sub>) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N<sub>2</sub>O). Carbon dioxide (CO<sub>2</sub>) from wastewater is not considered in the IPCC Guidelines because of its biogenic origin and should not be included in national total emissions.

Sludge is produced in all wastewater handling. It consists of solids that are removed from the wastewater. This sludge must be treated further before it can be safely disposed of. In Norway, some of the wastewater sludge is treated aerobically, emissions are then included in composting (CRF 5B). Some facilities treat sludge anaerobically, producing biogas. During this process, CH<sub>4</sub> is produced. Emissions from the use of the produced CH<sub>4</sub> are included in the energy and industry sectors. Emissions of CH<sub>4</sub> from such facilities, due to unintentional leakages during process disturbances or other unexpected events, are included in the source category – 5B.

Emissions from flaring have been included in the waste incineration sector (CRF 5C).

N<sub>2</sub>O emissions from sewage sludge applied on fields are not treated in this chapter and are included in the LULUCF sector according to the guidelines (IPCC 2006).

According to the Approach 1 and 2 key category analysis, CH<sub>4</sub> and N<sub>2</sub>O emissions from Domestic wastewater treatment and discharge (5D1) are key category in Level assessment. According to the Approach 2 key category analysis, CH<sub>4</sub> emissions from industrial wastewater (5D2) are key category in level and trend assessment.

The Norwegian wastewater treatment system is characterized by a few big and advanced aerobic wastewater treatment plants (WWTP) and many smaller WWTP. In 2021, 64 % of Norway's population was connected to high-grade treatment plants with biological and/or chemical treatment. Furthermore, 21 % of the population was connected to mechanical or other types of treatment, 12 % of the population was connected to small wastewater facilities (less than 50 pe) and the remaining 2 % had direct discharges.

There are around 2 750 wastewater facilities with a capacity of more than 50 population equivalents (pe) in Norway which treated wastewater from 88 % of the population in 2021. The source category 5D includes estimation of CH<sub>4</sub> and N<sub>2</sub>O emission from wastewater handling, i.e., wastewater collection and treatment. CH<sub>4</sub> is produced during anaerobic conditions and treatment processes, while N<sub>2</sub>O may be emitted as a by-product from nitrification and denitrification processes under anaerobic as well as aerobic conditions. It is not possible to fully distinguish between emissions from industrial and domestic wastewater, as Norwegian industries, to a great extent, are coupled to the municipal sewer system. Wastewater streams from households and industries are therefore mixed in the sewer system prior to further treatment at centralised WWTP.

Industrial wastewater may be treated on-site or released into domestic sewer systems. If it is released into the domestic sewer system, the emissions are included in the domestic wastewater emissions (CRF 5D1). Norway estimates CH<sub>4</sub> emissions from on-site industrial wastewater treatment not connected to domestic sewer systems. Only industrial wastewater with significant carbon loading that is treated under intended or unintended anaerobic conditions will produce CH<sub>4</sub>. Industries which have been considered are:

- Pulp and paper industry,
- Chemical industry,
- Food processing industries.

As a response to previous reviews, Norway has initiated collection of activity data from Norwegian industry to enhance completeness of emissions from wastewater handling. Norway has conducted investigations on industries with separate wastewater facilities in the chemical industry and has concluded that no company in this industry has anaerobic treatment of wastewater. In the food processing industry, all identified plants have aerobic treatment except from one. In this plant, the methane generated is flared.

Two companies in the pulp and paper industry have been identified as running anaerobic wastewater treatment facilities. The methane emissions generated from this treatment are either flared or used for energy purposes. Emissions from energy recovery have been included in energy combustion for Manufacturing Industries and construction (sector 1A2d) pulp, paper and print from 1991 when recovery began.

Emissions from flaring have been included in the waste incineration sector (CRF 5C).

## 7.6.2 Methodological issues

### 7.6.2.1 Domestic wastewater

#### 7.6.2.1.1 CH<sub>4</sub>

##### CH<sub>4</sub> from domestic wastewater treatment plants

Methane emissions from domestic wastewater have been calculated according to the IPCC default updated methodology (2019):

$$(7.12) \quad CH_4 \text{ Emissions} = \sum_j EF_j \times (TOW_j - S_j) - R_j$$

Where:

- U<sub>i</sub>: fraction of the population in income group i
- T<sub>ij</sub>: Degree of utilisation of treatment/discharge j, for each income group i
- EF<sub>j</sub>: Emission factor for treatment/discharge j, kg CH<sub>4</sub> / kg BOD

- TOW<sub>j</sub>: organics in wastewater of treatment/discharge pathway or system, j, in inventory year, kg BOD/yr.
- S<sub>j</sub> Organic component removed as sludge from treatment/discharge pathway or system, j (kg BOD / yr)
- R<sub>j</sub> Amount of CH<sub>4</sub> recovered from treatment/discharge pathway or system, j in the inventory yr.

Emissions have been estimated for all treatment types and for discharge into environment. In Norway, all domestic centralized wastewater treatment plants are aerobic and are considered well managed. 88 % of the population is connected to this type of treatment in 2021. The rest of the population is connected either to septic systems (for the most important part) or have direct discharge. CH<sub>4</sub> emissions are estimated according to IPCC updated methodology (2019).

#### 7.6.2.1.2 N<sub>2</sub>O

Emissions of nitrous oxide from domestic and commercial wastewater treatment have been estimated for both the part of the population connected to large wastewater treatment plants (WWTP) (>50 pe) and the part of the population not connected to large WWTP. The former includes the part of industries connected to the large.

##### N<sub>2</sub>O emissions from domestic wastewater treatment

N<sub>2</sub>O emissions from discharge of domestic wastewater and industries connected to large treatment plants (>50 pe) have been estimated based on nitrogen content in wastewater effluent.

For the largest plants with N-removal treatment, N<sub>2</sub>O emissions occurring as a by-product in biological nitrogen-removal plants has also been included into the calculations.

N<sub>2</sub>O emissions from domestic wastewater discharged have been calculated by multiplying the total amount of nitrogen discharged by the IPCC default emission factor of 0.005 kg N<sub>2</sub>O-N/kg N produced. Emissions in N needs to be converted into N<sub>2</sub>O using the conversion ratio of N into N<sub>2</sub>O: 44/28. Emissions have been estimated using equation (7.13).

$$(7.13) \quad N_2O = N_{supplied\ to\ pipelines} \times 0.005 \times \frac{44}{28}$$

N<sub>2</sub>O emissions in **biological nitrogen removal-plants** have been estimated using equation (7.14), assuming that 2 % in SFT (1990) of the nitrogen removed from the plants will form N<sub>2</sub>O.

$$(7.14) \quad N_2O = N_{removed} \times 0.02 \times \frac{44}{28}$$

The amount of N removed is multiplied by 2 % and emissions are then converted using the conversion ratio of N into N<sub>2</sub>O: 44/28.

Data on the amount of nitrogen removed in biological steps of the actual wastewater treatment plants is gathered from Statistics Norway's wastewater statistics.

#### 7.6.2.2 Industrial wastewater

Organic material in industrial wastewater is often expressed in terms of COD (chemical oxygen demand). CH<sub>4</sub> emissions from on-site industrial wastewater treatment are estimated based on the amount COD discharged. Emissions of methane from industrial wastewater are calculated according to the IPCC default methodology described in equation (7.15):

$$(7.15) \quad CH_4 = COD \times B_0 \times MCF$$

Where:

*COD*: chemical oxygen demand (industrial degradable organic component in wastewater)

*B<sub>0</sub>*: Maximum methane-producing capacity (kg CH<sub>4</sub>/kg COD)

*MCF*: Methane correction factor

N<sub>2</sub>O emissions from on-site industrial treatment are calculated according to the IPCC default methodology described in equation (7.16):

$$(7.16) \quad N_2O = N_{Effluent} \times EF_{Effluent} \times \frac{44}{28}$$

Where:

N<sub>2</sub>O: N<sub>2</sub>O emissions in inventory, kg N<sub>2</sub>O/year

*N<sub>Effluent</sub>*: content of nitrogen in the effluent

*EF<sub>Effluent</sub>*: emission factor for N<sub>2</sub>O emissions from discharge to wastewater

Emissions from the following industries are included in the Norwegian inventory:

- Pulp and paper industry

- Chemical industry
- Food processing industries

CH<sub>4</sub> and N<sub>2</sub>O emissions from industries connected to large treatment plants (>50 pe) are included in domestic wastewater handling sector (CRF 5D1).

### 7.6.3 Activity data

#### 7.6.3.1 Domestic wastewater

##### 7.6.3.1.1 CH<sub>4</sub> emissions from domestic WWTP

##### Treatment

Norwegian population data are extracted from Statistics Norway's population statistics. A country-specific value of 60 g BOD/person/day has been used for the degradable organic component value in domestic wastewater, for all years (Berge & Mellem 2013). For the largest plants which also include industry wastewater has BOD been adjusted with the use of correction factor for additional industrial BOD discharged recommended in the IPCC guidelines (2006).

The total organic product for domestic wastewater is presented in [Table 7.11](#).

| <b>Table 7.11 Total organic product treated in domestic wastewater.</b> |                                  |
|-------------------------------------------------------------------------|----------------------------------|
| Year                                                                    | Total organic product, tonnes DC |
| 1990                                                                    | 108 656                          |
| 1995                                                                    | 111 990                          |
| 2000                                                                    | 115 767                          |
| 2005                                                                    | 120 300                          |
| 2010                                                                    | 127 477                          |
| 2011                                                                    | 126 954                          |
| 2012                                                                    | 131 068                          |
| 2013                                                                    | 132 900                          |
| 2014                                                                    | 134 620                          |
| 2015                                                                    | 136 401                          |
| 2016                                                                    | 137 747                          |
| 2017                                                                    | 139 061                          |
| 2018                                                                    | 140 164                          |
| 2019                                                                    | 141 051                          |
| 2020                                                                    | 142 263                          |
| 2021                                                                    | 143 019                          |

Source: Statistics Norway/ Norwegian Environment Agency

### Discharge

Centralised wastewater treatment plants report degradable organic component discharged into the recipients to the authority. Reported data are directly used in the calculation. For the other wastewater treatment system degradable organic component discharged into the recipients is calculated based on the country-specific value of 60 g BOD/person/day and the removal fractions values recommended by the IPCC updated methodology (2019).

Table 7.12 presents the removal fractions values according to treatment type.

| <b>Table 7.12 Wastewater treatment organics removal fractions (TOWrem) according to treatment type.</b> |                                  |
|---------------------------------------------------------------------------------------------------------|----------------------------------|
| Year                                                                                                    | Total organic product, tonnes DC |
| Untreated system                                                                                        | 0                                |
| Primary (mechanical treatment plants)                                                                   | 0.40                             |
| Primary + Secondary (biological treatment plants)                                                       | 0.85                             |
| Primary + Secondary + Tertiary (advanced biological treatment plants)                                   | 0.90                             |
| Septic tank/septic system                                                                               | 0.625                            |
| Latrines – Dry climate, groundwater table lower than latrine, small family (3–5 persons)                | 0.1                              |
| Latrines – Dry climate, groundwater table lower than latrine, communal (many users)                     | 0.5                              |
| Latrines – Wet climate/flush water use, groundwater table higher than latrine                           | 0.7                              |

Source: IPCC updated methodology (2019)

The total organic product discharged into the environment is presented in Table 7.13.



| Table 7.13 Total organic product discharged into the environment from domestic wastewater. |                                  |
|--------------------------------------------------------------------------------------------|----------------------------------|
| Year                                                                                       | Total organic product, tonnes DC |
| 1990                                                                                       | 34 035                           |
| 1995                                                                                       | 34 773                           |
| 2000                                                                                       | 36 389                           |
| 2005                                                                                       | 35 106                           |
| 2010                                                                                       | 38 328                           |
| 2011                                                                                       | 45 910                           |
| 2012                                                                                       | 37 927                           |
| 2013                                                                                       | 39 860                           |
| 2014                                                                                       | 39 268                           |
| 2015                                                                                       | 40 805                           |
| 2016                                                                                       | 45 451                           |
| 2017                                                                                       | 38 782                           |
| 2018                                                                                       | 40 159                           |
| 2019                                                                                       | 39 026                           |
| 2020                                                                                       | 38 981                           |
| 2021                                                                                       | 38 986                           |

Source: Statistics Norway/ Norwegian Environment Agency

7.6.3.1.2 N<sub>2</sub>O emissions from large, small WWTP and domestic wastewater handling  
Data for the amount of nitrogen released into recipients are extracted from Statistics Norway's wastewater statistics.

Data is available for the period 1997-2021. For the period 1990-1996 nitrogen released into recipients is estimated based on 1997 amount and protein intake per capita estimated by the Directorate for Health and Social Affairs (Johansson L. Solvoll 1999). In 1997, the daily per capita protein intake for Norway amounted to 86 grams, corresponding to 31.39 kilos per person per year.

For the years 1990 and 1995, the Norwegian Directorate for Health has estimated the potential protein intake for the population (Directorate for Health and Social Affairs 2013). Potential protein intake has been estimated using equation (7.17):

$$(7.17) \text{ Potential protein intake} = \text{production} + \text{import} - \text{export}$$

This estimation assumes that all the products are eaten and does not take into consideration the food ending up as waste. To avoid overestimations, potential protein

intake is not used directly as protein intake in the inventory. Indeed, the trend of potential protein intake has been extrapolated to the protein intake estimated for 1997 (1.39 kilos per person) so as to build the time series from 1990 to 1996. These estimations rely on recommendations from the Directorate for Health and Social Affairs (Johansson, pers. Comm.<sup>39</sup>). Table 7.14 presents the potential protein intake in both g/person/day and kg/person/year and the estimated annual protein intake per capita.

**Table 7.14 Potential protein intake, and estimated protein intake, in g/person/day, kg/person/year, for the years 1990-1997.**

| Year | Potential protein intake<br>g/person/day | kg/person/year | Index<br>1997<br>=100 | Estimated protein<br>intake<br>kg/person/year |
|------|------------------------------------------|----------------|-----------------------|-----------------------------------------------|
| 1990 | <b>94</b>                                | 34.3           | 100.5                 | 31.56                                         |
| 1991 | 93.8                                     | 34.2           | 100.3                 | 31.49                                         |
| 1992 | 93.6                                     | 34.2           | 100.1                 | 31.42                                         |
| 1993 | 93.4                                     | 34.1           | 99.9                  | 31.36                                         |
| 1994 | 93.2                                     | 34.0           | 99.7                  | 31.29                                         |
| 1995 | <b>93</b>                                | 33.9           | 99.5                  | 31.22                                         |
| 1996 | 93.3                                     | 34.0           | 99.7                  | 31.31                                         |
| 1997 | <b>93.5</b>                              | 34.1           | 100                   | 31.39                                         |

*Numbers in bold come from the Norwegian Directorate for Health and Social Affairs*

Non-consumed protein has been taken into account in the estimation of protein added to wastewater. It has been set to 10 % of consumed protein. Therefore, Fncp, the factor for non-consumed protein added to wastewater has been set equal to 1.1.

### 7.6.3.2 Industrial wastewater

#### 7.6.3.2.1 CH<sub>4</sub> emissions from industrial WWTP

The amount COD discharged is reported by industries to the Norwegian Environment Agency.

**Table 7.15 Reported COD discharged by industries, in tonne/ year, for the years 1990-2021.**

| Year | COD released into recipient from industrial WWTP (tonne) |
|------|----------------------------------------------------------|
| 1990 | 143 446                                                  |
| 1995 | 124 982                                                  |

<sup>39</sup> Johansson, L. (2005): Personal information by telephone, Directorate for Health and Social Affairs

|      |        |
|------|--------|
| 2000 | 90 503 |
| 2005 | 84 502 |
| 2010 | 83 568 |
| 2011 | 78 778 |
| 2012 | 68 719 |
| 2013 | 62 712 |
| 2014 | 52 539 |
| 2015 | 52 731 |
| 2016 | 52 673 |
| 2017 | 57 082 |
| 2018 | 53 479 |
| 2019 | 49 055 |
| 2020 | 48 108 |
| 2021 | 46 709 |

*Source: Statistics Norway/ Norwegian Environment Agency*

#### 7.6.3.2.2 N<sub>2</sub>O emissions from industrial WWTP

N<sub>2</sub>O emissions from industries connected to large treatment plants (>50 pe) are included in domestic wastewater handling sector (CRF 5D1) while N<sub>2</sub>O emissions from industries with their own WWTP are calculated by a tier 2 method. The activity data are amounts of nitrogen in the effluent reported to the Norwegian Environment Agency.

| <b>Table 7.16 Reported Nitrogen discharged by industries, in tonne/year, for the years 1990-2021.</b> |                                                               |
|-------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|
| Year                                                                                                  | Nitrogen released into recipient from industrial WWTP (tonne) |
| 1990                                                                                                  | 416                                                           |
| 1995                                                                                                  | 624                                                           |
| 2000                                                                                                  | 753                                                           |
| 2005                                                                                                  | 709                                                           |
| 2010                                                                                                  | 820                                                           |
| 2011                                                                                                  | 914                                                           |
| 2012                                                                                                  | 783                                                           |
| 2013                                                                                                  | 1 077                                                         |
| 2014                                                                                                  | 832                                                           |
| 2015                                                                                                  | 882                                                           |
| 2016                                                                                                  | 970                                                           |
| 2017                                                                                                  | 941                                                           |
| 2018                                                                                                  | 967                                                           |
| 2019                                                                                                  | 867                                                           |
| 2020                                                                                                  | 831                                                           |
| 2021                                                                                                  | 844                                                           |

Source: Norwegian Environment Agency

## 7.6.4 Emission factors

### 7.6.4.1 CH<sub>4</sub> emissions from domestic WWTP

The default emission factor for B<sub>0</sub> of 0.6 kg CH<sub>4</sub>/kg BOD is used (IPCC 2006). The methane correction factor (MCF) is, according to good practice, given by the fraction of BOD that will ultimately degrade anaerobically. MCF values are taken from IPCC updated methodology (2019).

For treatment, MCF is assumed to be equal to 0.5 for the population connected to tanks with anaerobic conditions, 0.03 for the part of the population connected to centralized aerobic treatment plants and 0,1 for the part of the population connected to latrines. For discharge, MCF is assumed to be equal to 0.11.

Information on the part of the population connected to the different types of treatment are taken from Statistics Norway (wastewater statistics). [Table 7.17](#) gives an overview of the part of the population connected to centralized treatment plants, tanks with anaerobic conditions and other types of treatment (latrines, direct discharge) used in the Norwegian emission inventory.

| <b>Table 7.17 Part of the population connected to tanks with anaerobic conditions for the period 1990-2021.</b> |                                                                  |                                                                     |                                                             |
|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------|
| Year                                                                                                            | Part of the population connected to centralised treatment plants | Part of the population connected to tanks with anaerobic conditions | Part of the population connected to other type of treatment |
| 1990                                                                                                            | 75%                                                              | 23%                                                                 | 2%                                                          |
| 1995                                                                                                            | 77%                                                              | 22%                                                                 | 2%                                                          |
| 2000                                                                                                            | 78%                                                              | 20%                                                                 | 2%                                                          |
| 2005                                                                                                            | 82%                                                              | 17%                                                                 | 2%                                                          |
| 2010                                                                                                            | 83%                                                              | 15%                                                                 | 2%                                                          |
| 2011                                                                                                            | 83%                                                              | 15%                                                                 | 2%                                                          |
| 2012                                                                                                            | 84%                                                              | 15%                                                                 | 2%                                                          |
| 2013                                                                                                            | 84%                                                              | 14%                                                                 | 2%                                                          |
| 2014                                                                                                            | 84%                                                              | 14%                                                                 | 2%                                                          |
| 2015                                                                                                            | 85%                                                              | 14%                                                                 | 2%                                                          |
| 2016                                                                                                            | 85%                                                              | 14%                                                                 | 2%                                                          |
| 2017                                                                                                            | 85%                                                              | 14%                                                                 | 2%                                                          |
| 2018                                                                                                            | 85%                                                              | 13%                                                                 | 2%                                                          |
| 2019                                                                                                            | 85%                                                              | 13%                                                                 | 2%                                                          |
| 2020                                                                                                            | 86%                                                              | 12%                                                                 | 2%                                                          |
| 2021                                                                                                            | 86%                                                              | 12%                                                                 | 2%                                                          |

Source: Statistics Norway

#### 7.6.4.2 CH<sub>4</sub> emissions industrial WWTP

The default emission factor for B<sub>0</sub> of 0.25 kg CH<sub>4</sub>/kg COD is used (IPCC 2006). The methane correction factor (MCF) is assumed to be equal to 0.1 as the reported COD corresponds to amounts discharged by the plant, it is assumed untreated.

#### 7.6.4.3 N<sub>2</sub>O emissions from large WWTP

N<sub>2</sub>O emissions in **biological nitrogen removal-plants** have been estimated assuming that 2 % of the nitrogen removed from the plants will form N<sub>2</sub>O. This country-specific emission factor is given in SFT (1990). This assumption is based on measurements in plants and comparisons to factors used in Sweden. This emission factor is used for all plants except for one.

It has been hypothesized that one plant had a much higher performance, i.e., a lower percentage of processed N emitted as N<sub>2</sub>O. In 2011, N<sub>2</sub>O emissions were measured at

various spots within the treatment plant, as well as the concentrations of  $\text{N}_2\text{O}$  in the liquid phase throughout, including the exit water. The results verified that the performance of this process, with respect to  $\text{N}_2\text{O}$  emission, is much better than the emission factor used for the other treatment plants. On the average, the emission of  $\text{N}_2\text{O}$  -N to air from the entire plant (through the chimney) amounted to 0.2 % of the processed N. If the  $\text{N}_2\text{O}$  lost as dissolved  $\text{N}_2\text{O}$  in the exit water is included, the percentage increases to 0.3 (Bakken et al. 2012). For this WWTP, it has then been assumed that 0.3 % of the nitrogen removed from plants will form  $\text{N}_2\text{O}$ . This emission factor has been used for that plant for all years since 1996, the year when the nitrification and denitrification reactors were fully operational. For the period 1990-1996, the default emission factor of 2 % has been used.

#### **7.6.4.4 $\text{N}_2\text{O}$ emissions from other domestic wastewater handling**

For the part of the population that is not connected to large WWTP, IPCC default emission factors have been used:

- $\text{EF}_6$ : 0.005 kg  $\text{N}_2\text{O}$ /kg sewage-N produced has been used.
- $\text{Frac}_{\text{NPR}}$ , the fraction of nitrogen in protein, has been set equal to 0.16 kg N/kg protein.

#### **7.6.4.5 $\text{N}_2\text{O}$ emissions from on-site industrial WWTP**

IPCC default emission factor has been used for industries with on-site WWTP.

- $\text{EF}_{\text{Effluent}}$ : 0.005kg  $\text{N}_2\text{O}$ /kg sewage-N produced has been used.

### **7.6.5 Uncertainties and time-series consistency**

Uncertainty estimates for greenhouse gases are presented and discussed in Annex II. A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

### **7.6.6 Source specific QA/QC and verification**

See Section 1.2 for the description of the general QA/QC procedure.

In connection with the calculation of the 2021 emissions there has been a thorough review of the population of industry units with emissions of  $\text{CH}_4$  and NMVOC. The population consists of the units that rinse their own wastewater. During the review a system was designed to ensure that there are no fluctuations between years in future calculations.

### **7.6.7 Recalculations**

There have been several recalculations in 5D in the 2023 submission:

- 5D1 Domestic wastewater,  $\text{CH}_4$ : Updated activity data in 2020 led to a small reduction of  $\text{CH}_4$  emissions, -0.8 per cent.

- 5D1 Domestic wastewater, N<sub>2</sub>O: There has been a correction of error. A double count was identified and removed. The correction led to a reduction in N<sub>2</sub>O emissions in the whole timeseries. Details are given in chapter 10.
- 5D1 Domestic wastewater, NMVOC: There has been an update of the activity data, leading to an increase of 1.6 per cent in 2020 compared to the previous submission.
- 5D2 Industrial wastewater, CH<sub>4</sub> and NMVOC: The activity data was updated in the period of 1990-2020. These changes were made to ensure that the data was processed uniformly throughout the timeseries, and to assure that it is also processed in the same way in the years to come. Details on the changes can be found in chapter 10.
- 5D2 Industrial wastewater, N<sub>2</sub>O: There is reduced emissions of N<sub>2</sub>O in the whole timeseries due to a change in the population of industry units included in the calculation. Details on the changes can be found in chapter 10.

#### **7.6.8 Planned improvements**

Emissions from the amount of CH<sub>4</sub> that is flared or recovered for energy use has been reported to the energy sector and should be subtracted from total emissions. Following up 2016 review, Norway has begun to investigate possible double counting between emissions from wastewater treatment and emissions from flaring included in sector 1A2 (manufacturing industries and construction). The results of this investigation are not yet finished and will be presented in the next submission.

## **7.7 Other emissions sources from the waste sector – 5E**

### **7.7.1 Description**

No GHG emissions are currently included in this category.

### **7.7.2 Recalculations**

No recalculation has been made in this category.

### **7.7.3 Planned improvements**

There is currently no planned improvement for this source category.

## 8. Other (CRF sector 6) (if applicable)

Norway does not report any emissions in the *Other* source category.



## 9. Indirect carbon dioxide and nitrous oxide emissions

### 9.1 Description of sources of indirect emissions in the GHG inventory

#### 9.1.1 Indirect carbon dioxide emissions

According to the IPCCs 2006 Guidelines, most of the carbon emitted in the form of non-CO<sub>2</sub> species eventually oxidises to CO<sub>2</sub> in the atmosphere. The 2006 Guidelines further states that this can be estimated from the emission estimates of the non-CO<sub>2</sub> gases and that these CO<sub>2</sub> inputs could be included in national inventories. Norway includes such CO<sub>2</sub> inputs in its inventory, and these are referred to as indirect CO<sub>2</sub>. The indirect CO<sub>2</sub> emissions from non-combustion sources originating from the fossil part of CH<sub>4</sub> and NMVOC are taken into account, calculated on the basis of average carbon content. Fossil carbon in the emissions of CH<sub>4</sub> and NMVOC from several non-combustion sources are included in the Norwegian emission inventory, see [Table 9.1](#).

**Table 9.1 Source categories in the inventory where indirect CO<sub>2</sub> emissions is calculated for CH<sub>4</sub> and NMVOC.**

|                                                                                                                                                                                                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.B.1.a: Coal Mining and Handling                                                                                                                                                                |
| 1.B.2.a.3: Oil and Natural Gas and Other Emissions from Energy Production; Oil; Transport                                                                                                        |
| 1.B.2.a.4: Oil and Natural Gas and Other Emissions from Energy Production; Oil; Refining/Storage                                                                                                 |
| 1.B.2.a.5: Oil and Natural Gas and Other Emissions from Energy Production; Oil; Distribution of Oil Products                                                                                     |
| 1.B.2.b.5: Oil and Natural Gas and Other Emissions from Energy Production; Natural Gas; Distribution                                                                                             |
| 1.B.2.b.6: Oil and Natural Gas and Other Emissions from Energy Production; Natural Gas; Other (Gas terminals)                                                                                    |
| 1.B.2.c: Oil and Natural Gas and Other Emissions from Energy Production; Venting and Flaring (Includes diffuse emissions from oil and gas exploration and production (1.B.2.a.1-2, 1.B.2.b.1-2)) |
| 2.B.5: Carbide Production                                                                                                                                                                        |
| 2.B.8.a: Petrochemical and Carbon Black Production; Methanol                                                                                                                                     |
| 2.B.8.b: Petrochemical and Carbon Black Production; Ethylene                                                                                                                                     |
| 2.B.8.c: Petrochemical and Carbon Black Production; Ethylene Dichloride and Vinyl Chloride Monomer (included in 2.B.8.b in the reporting)                                                        |
| 2.B.8.g: Petrochemical and Carbon Black Production; Plastic                                                                                                                                      |
| 2.C.2: Ferroalloys Production                                                                                                                                                                    |
| 2.D.3: Solvent use                                                                                                                                                                               |
| 2.D.3: Road paving with asphalt                                                                                                                                                                  |

Indirect CO<sub>2</sub> emissions from CO is not included in the inventory as all carbon is included in the emission factors and hence additional estimation of indirect CO<sub>2</sub> emissions of CO would imply double counting.

### 9.1.2 Indirect nitrous oxide emissions

Indirect emissions of N<sub>2</sub>O can occur by several pathways. The agriculture sector covers indirect emissions from deposition of NO<sub>x</sub> and NH<sub>3</sub> from agriculture sources as well as indirect emissions from leakage and runoff (see chapter 5.4.1.9 and 5.4.1.10). This chapter covers indirect emissions of N<sub>2</sub>O from deposition of NO<sub>x</sub> and NH<sub>3</sub> emissions from other sectors. These N<sub>2</sub>O emissions are included as memo items in the inventory.

The coverage of the indirect N<sub>2</sub>O emissions in CRF Table 6 is listed in Table 9.2 below. The energy sector is the primary source, and NO<sub>x</sub> from the energy sector comprised around 90 per cent of the total CRF Table 6 emissions in 2021.

**Table 9.2. Source categories in the inventory where indirect N<sub>2</sub>O emissions is reported in CRF Table 6 as memo items.**

|                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 Energy: Indirect <b>N<sub>2</sub>O</b> from all emissions of <b>NO<sub>x</sub></b> and <b>NH<sub>3</sub></b> in the energy sector                                                                                                                                                                                                                                      |
| 2 Industrial processes and product use: Indirect <b>N<sub>2</sub>O</b> from all emissions of <b>NO<sub>x</sub></b> and <b>NH<sub>3</sub></b> in the IPPU sector                                                                                                                                                                                                          |
| 3 Agriculture:<br>Indirect <b>N<sub>2</sub>O</b> from emissions of <b>NO<sub>x</sub></b> and <b>NH<sub>3</sub></b> in source category 3F Field burning of agricultural residues.<br><br>All other indirect <b>N<sub>2</sub>O</b> emissions from agricultural <b>NO<sub>x</sub></b> and <b>NH<sub>3</sub></b> are included in the inventory proper in source category 3D. |
| 4 Land use, land use change and forestry: No estimated <b>NO<sub>x</sub></b> and <b>NH<sub>3</sub></b> emissions and thus no indirect <b>N<sub>2</sub>O</b> emissions.                                                                                                                                                                                                   |
| 5 Waste: Indirect <b>N<sub>2</sub>O</b> from all emissions of <b>NO<sub>x</sub></b> and <b>NH<sub>3</sub></b> in the waste sector <i>except</i> <b>NH<sub>3</sub></b> emissions from composting. Indirect emissions from composting are assumed to be covered in the agriculture sector.                                                                                 |

## 9.2 Methodological issues

### 9.2.1 Methodological issues for indirect carbon dioxide emissions

The indirect CO<sub>2</sub> emissions from oxidised CH<sub>4</sub> and NMVOC are calculated from the content of fossil carbon in the compounds. For CH<sub>4</sub>, the factor for indirect emissions is simply calculated on basis of mass of molecules. For NMVOC the average carbon fraction is also taken into account. The default value for carbon fraction, 0.6, is used. This leads to the emission factors 2.75 kg CO<sub>2</sub>/kg CH<sub>4</sub>, and 2.2 kg CO<sub>2</sub>/kg NMVOC. The NMVOC factor is used

for all other source categories than NMVOC from loading and storage of crude oil offshore and from gasoline distribution. For loading and storage of crude oil we use the emission factor 3.0 kg CO<sub>2</sub> per kg NMVOC from CMR Instrumentation (CMR 2011). For gasoline distribution we use the emission factor 3.13 kg CO<sub>2</sub> per kg NMVOC, which is the same as the emission factor as for combustion of gasoline. More details for the relevant source categories are found in the relevant chapters of the NIR.

### 9.2.2 Methodological issues for indirect nitrous oxide emissions

The indirect N<sub>2</sub>O emissions from deposition of NO<sub>x</sub> and NH<sub>3</sub> are estimated according to the method in vol 1, ch 7.3.1 of the IPCC 2006 Guidelines (IPCC 2006). The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/(kg NH<sub>3</sub>-N+NO<sub>x</sub>-N volatilized) is used to calculate indirect emissions of N<sub>2</sub>O from volatilized NH<sub>3</sub> and NO<sub>x</sub> (IPCC 2006, vol 4, table 11.4 ). The factor is taken from the methodology for indirect emissions in the agriculture sector.

## 9.3 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex II. A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

## 9.4 Category-specific QA/QC and verification

The general QA/QC methodology is given in Annex V and the specific QA/QC carried out for indirect CO<sub>2</sub> emissions in the relevant source categories in Energy and IPPU are found in chapters 3 and 4 of the NIR.

The indirect N<sub>2</sub>O emissions are based on NO<sub>x</sub> and NH<sub>3</sub> emissions as reported under the UNECE Convention on Long-range Transboundary Pollution. The QA/QC methodology for this reporting is found in the annual Informative Inventory Report (NEA 2022).

## 9.5 Category-specific recalculations

The indirect CO<sub>2</sub> emissions were previously an integral part of the reported emissions under the sectors Energy and IPPU. Since the indirect CO<sub>2</sub> emissions were an integral part of the emission estimates, they were included in the sums named "Total CO<sub>2</sub> equivalent emissions without land use, land-use change and forestry" and "Total CO<sub>2</sub> equivalent emissions with land use, land-use change and forestry" in the summary tables in the CRF Reporter. In order to achieve correct totals including indirect CO<sub>2</sub>, table 6 of the CRF Reporter did not include indirect CO<sub>2</sub> emissions, as this would have led to double counting in the summary table totals "including indirect CO<sub>2</sub>".

The expert review team of the 2020 NIR recommended Norway to report in the CRF tables and in the NIR the national totals with and without indirect CO<sub>2</sub> in line with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines, making relevant changes to its sectoral level reporting as necessary. This recommendation has been implemented in the NIR and CRF reported in 2023. Thus, indirect CO<sub>2</sub> emissions previously reported in Energy and IPPU have been reallocated from these two sectors to CRF table 6 (see table 9.3 for level and trend).

**Table 9.2 Indirect CO<sub>2</sub> emissions (ktonnes) from CH<sub>4</sub> and NMVOC.**

| Year | Energy | IPPU  | Agriculture | LULUCF | Waste | Total   |
|------|--------|-------|-------------|--------|-------|---------|
| 1990 | 471.8  | 120.9 | NA          | NA     | NE    | 592.7   |
| 1995 | 767.7  | 115.0 | NA          | NA     | NE    | 882.7   |
| 2000 | 885.1  | 111.0 | NA          | NA     | NE    | 996.1   |
| 2001 | 926.9  | 113.4 | NA          | NA     | NE    | 1 040.3 |
| 2002 | 789.8  | 114.9 | NA          | NA     | NE    | 904.7   |
| 2003 | 654.4  | 115.5 | NA          | NA     | NE    | 769.9   |
| 2004 | 555.3  | 117.9 | NA          | NA     | NE    | 673.2   |
| 2005 | 424.4  | 106.9 | NA          | NA     | NE    | 531.2   |
| 2010 | 212.2  | 95.7  | NA          | NA     | NE    | 307.8   |
| 2012 | 189.4  | 101.0 | NA          | NA     | NE    | 290.4   |
| 2013 | 196.9  | 104.4 | NA          | NA     | NE    | 301.3   |
| 2014 | 222.3  | 117.1 | NA          | NA     | NE    | 339.4   |
| 2015 | 217.0  | 110.8 | NA          | NA     | NE    | 327.7   |
| 2016 | 200.5  | 117.8 | NA          | NA     | NE    | 318.3   |
| 2017 | 179.2  | 123.0 | NA          | NA     | NE    | 302.2   |
| 2018 | 181.4  | 116.3 | NA          | NA     | NE    | 297.8   |
| 2019 | 168.9  | 91.5  | NA          | NA     | NE    | 260.4   |
| 2020 | 156.9  | 126.1 | NA          | NA     | NE    | 283.0   |
| 2021 | 130.5  | 126.3 | NA          | NA     | NE    | 256.9   |

## 9.6 Category-specific planned improvements

There are no planned activities this year that will improve the data quality or the documentation for this source category.

## 10. Recalculations and improvements

### 10.1 Explanations and justifications for recalculations

Every year, the Norwegian greenhouse gas emission inventory is calculated for all years in the time series, starting in 1990, and for all components and sources. This recalculation is done in order to account for new knowledge on activity data and emission factors, and to correct for discovered errors in the calculations.

There is a continuous process for improving and correcting the inventory and the documentation of the methodologies employed, based on questions and comments received in connection with the annual reviews performed by the expert review teams (ERTs) under the UNFCCC. The figures in this inventory are, as far as possible, consistent through the whole time series.

The driving force for making improvements in the emission inventory is to meet the reporting requirements in the UNFCCC Reporting Guidelines. In addition, it is important for decision makers and others to have accurate emission estimates as basis for making decisions of what measures to introduce to reduce emissions.

The first section (section 10.2) in this chapter provides detailed descriptions of recalculations for each sector and gas. Even though the inventory as a whole is calculated every year, this does not imply that all sectors and gases will have changes in estimated emissions that result from changes in methodologies, changes in the manner in which EFs and AD are obtained and used, or the inclusion of new sources or sinks. Most emission estimates remain unchanged between production cycles. Further, small differences in estimates of emissions and removals are not considered to be recalculations. Therefore, all changes in estimates greater than 2 percent are explained in section 10.2. Changes of smaller magnitude are also included, if they are a result of changes in methodology or data sources or otherwise deemed significant enough to be classified as recalculations by the inventory group.

The overall impacts of these recalculations on total emission levels and trends are given in section 10.3. An overview of issues identified by the UN review team and Norway's responses to these issues can be found in the last section of this chapter (section 10.4).

## 10.2 Specific description of the recalculations

In 2023, the emission inventory has been recalculated using GWPs from AR5, rather than AR4. Also, indirect emissions of CO<sub>2</sub> from CH<sub>4</sub> and NMVOC are now excluded from sectoral totals, and reported separately in CRF tables summary 2, 6 and 10. The reallocation of indirect CO<sub>2</sub> emissions affect the following CRF sources:

- 1.B.1.a: Coal Mining and Handling
- 1.B.2.a.3: Oil and Natural Gas and Other Emissions from Energy Production; Oil; Transport
- 1.B.2.a.4: Oil and Natural Gas and Other Emissions from Energy Production; Oil; Refining/Storage
- 1.B.2.a.5: Oil and Natural Gas and Other Emissions from Energy Production; Oil; Distribution of Oil Products
- 1.B.2.b.5: Oil and Natural Gas and Other Emissions from Energy Production; Natural Gas; Distribution
- 1.B.2.b.6: Oil and Natural Gas and Other Emissions from Energy Production; Natural Gas; Other (Gas terminals)
- 1.B.2.c: Oil and Natural Gas and Other Emissions from Energy Production; Venting and Flaring (Includes diffuse emissions from oil and gas exploration and production (1.B.2.a.1-2, 1.B.2.b.1-2))
- 2.B.5: Carbide Production
- 2.B.8.a: Petrochemical and Carbon Black Production; Methanol
- 2.B.8.b: Petrochemical and Carbon Black Production; Ethylene
- 2.B.8.c: Petrochemical and Carbon Black Production; Ethylene Dichloride and Vinyl Chloride Monomer (included in 2.B.8.b in the reporting)
- 2.B.8.g: Petrochemical and Carbon Black Production; Plastic
- 2.C.2: Ferroalloys Production
- 2.D.3: Solvent use
- 2.D.3: Road paving with asphalt

The implications for emission levels and trends are described in chapter 10.3.

### 10.2.1 Energy

Most of the recalculations have been performed for the inventory year 2020, because some of the energy figures for the last year in the inventory are preliminary due to data availability to the energy balance. There will always be some changes in the energy figures, mainly because more detailed energy data result in changes in allocation between sectors. For petroleum products, corrections in one sector will lead to adjustments in other sectors, as total use of oil products must sum up to national sales. Now the final figures for energy use are available and are used in the emission calculations. Changes in the emission

figures due to such changes in the energy statistics will not be commented on specifically under each CRF code.

As described in chapter 10.2, indirect emissions of CO<sub>2</sub> are now excluded from sectoral totals, and reported separately in CRF tables summary 2, 6 and 10. Chapter 10.2 identifies the relevant source categories within the Energy sector for where the indirect CO<sub>2</sub> emissions have been reallocated and these are not included in the list below.

#### **10.2.1.1 1A1ai Electricity generation**

- Correction of emission data for 2019 and 2020.
- The increased emissions of N<sub>2</sub>O for 2012 – 2016 is due to an increase in the energy figures for wood waste.

#### **10.2.1.2 1A1aiii Heat Plants**

- The amounts of waste in the calculations for the energy statistics were previously higher than there was a basis for. These have therefore been adjusted down, which resulted in lower energy and thus lower emissions.

#### **10.2.1.3 1A1b Petroleum refining**

- Correction of emission data for CO<sub>2</sub> for one large unit in 2019
- The increased emissions of N<sub>2</sub>O for years 1990-2020 is due to a change in emission factors when energy previously classified as petroleum coke gas now is classified as blast furnace gas.

#### **10.2.1.4 1A1cil Manufacture of solid fuels**

- Increased emissions for the years 2007-2018 is due to increased activity data of diesel.

#### **10.2.1.5 1A2a Iron and steel**

- Revised activity data for blast furnace gas caused small changes in CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in the period 2008-2010 and in 2012.
- Transparency. We discovered an allocation issue for one plant, which had been contributing to high variability in the CO<sub>2</sub> IEF in later years. While the energy from its auto-consumed blast furnace gas had been placed in 1A2A, the CO<sub>2</sub> from this gas was included in 2C1a. This results in the very small decreases in CH<sub>4</sub> and N<sub>2</sub>O that was calculated from this gas in the period 2011-2020, on average 20 and 10 kg, respectively.

#### **10.2.1.6 1A2b Non-ferrous metals**

- Correction of error. CO<sub>2</sub> from the use of petrol coke as fuel was removed from two aluminium plants in the period 2009-2020, as the emissions were already included in the IPPU sector. CO<sub>2</sub> emissions decreased by 8 kt on average.
- Correction of a double counting of light fuel oil AD causes minor decreases in CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in 1997.

#### **10.2.1.7 1A2b Non-ferrous metals /1A2f Non-metallic minerals**

- Correction of error and allocation. Consumption of petrol coke was reallocated from one plant in 1A2f to a related one in 1A2b in the period 2008-2020. The CO<sub>2</sub> emissions from the petrol coke were already accounted for in the IPPU sector, and so were solely removed from 1A2F. CH<sub>4</sub> and N<sub>2</sub>O were reallocated.

#### **10.2.1.8 1A2c Chemicals**

- Correction of CO<sub>2</sub> emissions. Directly reported emissions from one plant were removed due to emissions not corresponding to energy use in the energy data. Emissions from diesel and light fuel oil from this plant are now calculated from energy use in the energy data x EF.
- Correction of double counting of heavy distillate in 1997, resulting in a reduction of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

#### **10.2.1.9 1A2f Non-metallic minerals**

- Revised activity data for the years 1996 to 2002 resulting in a small change in emissions of CO<sub>2</sub> and N<sub>2</sub>O.
- Correction of AD earlier classified as solid fuels, reallocated as waste and to other fossil fuels. Resulting in a decrease in emissions of CO<sub>2</sub> and an increase of the emissions of CH<sub>4</sub> in the period from 2013-2020.

#### **10.2.1.10 1A2giii Mining and quarrying**

- Revised activity data in 2010 resulting in a small reduction of CO<sub>2</sub> emissions.

#### **10.2.1.11 1A2gvii Off-road vehicles and other machinery - Manufacturing and construction**

- The activity data in the energy balance was changed from 2010-2020 due to revised activity data on 1A3c railways. Some liquid fuels from 2007-2013 were reallocated to 1A1ci Manufacture of solid fuels.

#### **10.2.1.12 1A3a Domestic aviation**

- Activity data from respondents has been updated and resulted in higher domestic and international activity and emissions for the years 2019-2020.



**10.2.1.13 1A3b Road transport**

- The activity data and emission factors were revised in the time series 1990-2020 due to the new version of HBEFA 4.2 (INFRAS 2019), and national data updates in the model (load and transformation pattern on HGV, and traffic situations). This resulted in reallocation of activity data on the vehicle segments and affects all emissions.

**10.2.1.14 1A3c Railways**

- Revised activity data in the energy balance in the time series 2010-2020 resulted in changes in emissions.

**10.2.1.15 1A3d Domestic Navigation/1A4ciii Fishing**

- Revised activity data from the energy balance in the years 2010-2014. Reallocation of emissions from domestic navigation to fishing and international bunkers.

**10.2.1.16 1A3d Domestic navigation/1A5b Military**

- Reallocation of emissions from LNG used in military vessels that was erroneously placed under Domestic navigation in the previous submissions.

**10.2.1.17 1A4ai Stationary**

- Revised activity data from the energy balance and correction of double-counting of natural gas consumption in the years 2019-2020, resulting in reduced emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

**10.2.1.18 1A4aii Off-road vehicles and other machinery - Commercial/Institutional**

- The activity data in the energy balance was changed from 2010-2020 due to revised activity data on 1A3c railways.

**10.2.1.19 1A4bi Stationary**

- Revised activity data from the energy balance in the years 2019-2020 and corrections to firewood consumption in 2020, resulting in slightly reduced emissions of CH<sub>4</sub> and N<sub>2</sub>O in 2019 and 2020, and a larger decrease in CO<sub>2</sub> emissions in 2020.

**10.2.1.20 1A4bii Off-road vehicles and other machinery - Households**

- Recalculated emissions in 2020 due to revised activity data on snow scooters.
- Recalculated emissions from 1990-2020 caused by changes in emission factors for snow scooters. Snow scooters have the same emission factors as mopeds in road transportation and are affected by these new factors (CH<sub>4</sub> and N<sub>2</sub>O).

**10.2.1.21 1A4ci Stationary**

- Revised activity data from the energy balance in the year 2020, resulting in reduced emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O.

**10.2.1.22 1A5bii Lubricants – two stroke engines**

- Revised activity data. The amounts of lubricants used in two stroke engines were updated and led to a slight increase in the emissions of CO<sub>2</sub> in the period 2010-2020. The increase is a total of 92.5 tonnes, increasing from a change of 2 tonnes in 1990 to 17 tonnes in 2020.

**10.2.1.23 1B1A1iii Abandoned Underground Mines**

- Emission factors were updated according to the IPCC 2019 refinements, resulting in some slight changes in CH<sub>4</sub> emissions for the years 2017-2020.

**10.2.1.24 1B2c2ii Gas**

- New emission data for CO<sub>2</sub> for 2018.

**10.2.2 Industrial processes and product use**

As described in chapter 10.2, indirect emissions of CO<sub>2</sub> are now excluded from sectoral totals, and reported separately in CRF tables summary 2, 6 and 10. Chapter 10.2 identifies the relevant source categories within the IPPU sector for where the indirect CO<sub>2</sub> emissions have been reallocated and these are not included in the list below.

**10.2.2.1 2B8g plastic**

Revised activity data for two plants, resulting in a decrease in CO<sub>2</sub> emissions in the period 1990 to 2018, with largest impact in 2005 and 2006 with a reduction of 4kt and 8kt respectively.

**10.2.2.2 2F1 Refrigeration and Air conditioning**

Reallocation of import: The distribution of imported HFC-134a in 2019 and 2020 was not correctly distributed between the subsectors but included as a total in 2.F.1.e Mobile Air-conditioning. In the present submission the import has been reallocated between the subsectors.

Updated activity data: The activity data was updated in 2019 due to updated information on imports.

Correction of error: An error in the calculations was discovered in the period of 2010-2020 for subsector 2.F.1.e. The effect of the error is minor and below 0.5 per cent before 2019.

The total change in the period 2010-2018 is an increase of 1 895 tonnes CO<sub>2</sub> equivalents compared to the 2022 submission.

The total change in emissions in 2019 and 2020 are given in [Table 3.1](#) below.

| <b>Table 10.1 Changes in HFC emissions due to recalculations in 2F1, compared to the 2022 submission</b> |                                      |                   |                  |                                       |
|----------------------------------------------------------------------------------------------------------|--------------------------------------|-------------------|------------------|---------------------------------------|
|                                                                                                          | 2019                                 |                   | 2020             |                                       |
|                                                                                                          | Change in tonnes, CO <sub>2</sub> eq | Percentage change | Change in tonnes | Percentage change, CO <sub>2</sub> eq |
| <b>2.F.1.a</b>                                                                                           | 17 4340                              | 10.4              | 28 856           | 1.7                                   |
| <b>2.F.1.b</b>                                                                                           | 4                                    | 0.1               | 6                | 0.1                                   |
| <b>2.F.1.c</b>                                                                                           | -24 723                              | -25.9             | 104              | 2.6                                   |
| <b>2.F.1.d</b>                                                                                           | -2 522                               | -5.5              | -1 013           | -4.9                                  |
| <b>2.F.1.e</b>                                                                                           | 3 784                                | 1.2               | -5 155           | -1.7                                  |
| <b>2.F.1.f</b>                                                                                           | 5 733                                | 2.7               | 1 718            | 0.8                                   |

Source: Statistics Norway/Norwegian Environment Agency

### 10.2.3 Agriculture

#### 10.2.3.1 Animal population

The animal number for sheep was revised for 2020 as a result of updated information. The updated numbers were estimated 2% higher for both sheep > and < one year compared to previous submission.

#### 10.2.3.2 3A CH<sub>4</sub> from enteric fermentation

No methodological changes were introduced in the 2023 submission for enteric fermentation. However, a change in the animal weight for young cattle in 2020 led to 1 per cent higher emissions, and revised animal number for sheep resulted in 2 per cent higher emissions of enteric methane compared to earlier submission.

#### 10.2.3.3 3B N<sub>2</sub>O and CH<sub>4</sub> from manure management

In 2022, a project with evaluating and updating existing N<sub>ex</sub> and VS factors for cattle was performed by the Norwegian University of Life Sciences (NMBU). This resulted in a revised VS factor for young cattle. The new VS factor was as before based on the calculation suggested by Karlengen et al. (2012), but included an updated organic matter factor. The results of the N<sub>ex</sub> and VS project is explained in Volden (2022). This led to a change in VS factor for young cattle throughout the whole time series, and 3 per cent higher methane

emissions per year as an average compared to the 2022 submission as showed in [Table 10-2](#).

| <b>Table 10-2 Changes in methane emissions because of revised VS factors for young cattle.</b> |                                            |                                    |                                            |                                    |                     |
|------------------------------------------------------------------------------------------------|--------------------------------------------|------------------------------------|--------------------------------------------|------------------------------------|---------------------|
|                                                                                                | 2022- submission                           |                                    | 2023- submission                           |                                    | Change in emission% |
| <b>Year</b>                                                                                    | VS-factor<br>[kg organic matter/head/year] | CH <sub>4</sub> emission<br>tonnes | VS-factor<br>[kg organic matter/head/year] | CH <sub>4</sub> emission<br>tonnes |                     |
| <b>1990</b>                                                                                    | 681                                        | 2532                               | 676                                        | 2516                               | -0.6                |
| <b>2000</b>                                                                                    | 660                                        | 2508                               | 690                                        | 2625                               | 4.7                 |
| <b>2010</b>                                                                                    | 786                                        | 2591                               | 808                                        | 2665                               | 2.8                 |
| <b>2020</b>                                                                                    | 838                                        | 2793                               | 857                                        | 2846                               | 1.9                 |

The VS factors showed in [Table 10-2](#) is a weighted average of the factors for heifer for replacement, bulls for slaughter and heifers for slaughter. Updated VS factors gave as an average 40 per cent lower factor for heifer for breeding, 29 per cent higher factors for bulls for slaughter and 74 per cent higher factor for heifer for slaughter was. Since the combination of number of animals in different groups of young cattle varies through the time series the difference between old and new estimation also varies. In 1990 to 1991 the updated estimation gave lower emissions but from 1992 to 2020 the updated factors gave higher emissions compared to earlier submission.

The activity data concerning manure management systems from 2019 to 2020 was updated in submission 2023 due to new data from Statistics Norway's census of agriculture 2020. This led to a change in the storage of manure data and a change in 3B methane emissions for 2019 and 2020. The changes in emissions for 3B are showed in [Table 10-3](#).

| Table 10-3 Changes in methane emissions from manure management systems due to updated activity data |                 |      |       |       |       |        |         |                            |        |
|-----------------------------------------------------------------------------------------------------|-----------------|------|-------|-------|-------|--------|---------|----------------------------|--------|
|                                                                                                     | Sub-<br>mission | Year | Sheep | Swine | Goats | Horses | Poultry | Fur-<br>bearing<br>animals | Total  |
| <b>Emissions<br/>tonnes CH<sub>4</sub></b>                                                          | 2022            | 2019 | 739   | 2 166 | 84    | 1 076  | 384     | 31                         | 14 620 |
|                                                                                                     | 2023            | 2019 | 727   | 2 128 | 81    | 982    | 359     | 27                         | 14 527 |
| <b>Changes %</b>                                                                                    |                 | 2019 | -1.6  | -1.8  | -2.8  | -8.8   | -6.4    | -11.5                      | -0.6   |
| <b>Emissions<br/>tonnes CH<sub>4</sub></b>                                                          | 2022            | 2020 | 733   | 2 086 | 85    | 1 089  | 380     | 18                         | 14 582 |
|                                                                                                     | 2023            | 2020 | 724   | 2 014 | 80    | 865    | 365     | 14                         | 14 282 |
| <b>Changes %</b>                                                                                    |                 | 2020 | -1.2  | -3.5  | -5.5  | -20.6  | -3.7    | -22.9                      | -2.1   |

The N<sub>2</sub>O emissions from 3B were recalculated for 2019 and 2020 in the 2023 submission. This was caused by the implementation of new activity data on manure management systems. This led to higher emissions for cattle, sheep and horses and lower emissions for swine, goat and poultry as showed in Table 10-4.

| Table 10-4 Changes in direct N <sub>2</sub> O emissions from manure management systems due to updated activity data |            |      |       |       |       |        |         |       |
|---------------------------------------------------------------------------------------------------------------------|------------|------|-------|-------|-------|--------|---------|-------|
|                                                                                                                     | Submission | Year | Sheep | Swine | Goats | Horses | Poultry | Total |
| <b>Emission<br/>tonnes<br/>N<sub>2</sub>O</b>                                                                       | 2022       | 2019 | 25.7  | 10.0  | 3.1   | 23.7   | 8.9     | 326.0 |
|                                                                                                                     | 2023       | 2019 | 27.6  | 9.4   | 3.0   | 27.6   | 8.3     | 335.0 |
| <b>Changes %</b>                                                                                                    |            |      | 7.3   | -5.3  | -1.7  | 16.5   | -6.5    | 2.8   |
| <b>Emission<br/>tonnes<br/>N<sub>2</sub>O</b>                                                                       | 2022       | 2020 | 25.4  | 9.6   | 3.1   | 24.0   | 8.8     | 324.0 |
|                                                                                                                     | 2023       | 2020 | 29.9  | 8.5   | 3.0   | 32.3   | 8.5     | 346.6 |
| <b>Changes %</b>                                                                                                    |            |      | 17.5  | -11.0 | -1.7  | 34.8   | -3.8    | 7.0   |

3Bb5 Indirect N<sub>2</sub>O from manure management: For the animal category “heifers for breeding” an error in the calculation of TAN factor (total ammonia nitrogen) was found and corrected in 2022. This led to a change in the NH<sub>3</sub> and NO<sub>x</sub> basis to form N<sub>2</sub>O, and a

recalculation for indirect N<sub>2</sub>O from manure management. The N<sub>2</sub>O emissions from 1990 to 2020 were 1.4 per cent higher as an average in the 2023 submission compared to the previous submission.

#### **10.2.3.4 3D2a Animal manure applied to soils**

There has been a change in total NH<sub>3</sub> emissions from spreading of manure due to a technical correction in the Norwegian model for calculating nitrogen emissions from manure. The whole time series for NH<sub>3</sub> emissions from spreading has been recalculated resulting in approximately 11 per cent higher NH<sub>3</sub> emissions per year compared to 2022 submission. This led to a recalculation for the whole time series for 3Db, indirect N<sub>2</sub>O emissions from managed soils, atmospheric deposition. This is further mentioned in 10.2.3.7.

Improvement and correction of error: Updated figures from Statistics Norway census of agriculture 2020 gave new information about spreading practice and incorporation time. The whole time series back to 1990 was revised since inconsistencies in earlier calculation were discovered. This only led to minor changes in the N<sub>2</sub>O emissions from 1990 to 2018, by minus 0.3 per cent on average. For 2019 and 2020, the years that were affected by new activity data on spreading techniques and incorporation time, gave 0.1 and 1.4 per cent higher N<sub>2</sub>O emissions compared to former submission.

#### **10.2.3.5 3Da4 N<sub>2</sub>O from crop residues**

For the emission of N<sub>2</sub>O from crop residues there has been changes in the 2023 submission due to updated activity data in 2020. This led to 3 per cent higher N<sub>2</sub>O emission in 2020 compared to the 2022 submission.

#### **10.2.3.6 3Da6 N<sub>2</sub>O from cultivation of organic soils**

For 3Da6, N<sub>2</sub>O from cultivation of organic soils, the whole time series has been recalculated due to updated area estimates of organic soil from NIBIO. This led to a change of 6 percent lower N<sub>2</sub>O emissions on average throughout the time series compared to the 2022 submission.

#### **10.2.3.7 3Db1 Atmospheric deposition from managed soils**

Correction of error: In 2022 the Nitrogen model was corrected due to a wrong calculation of NO<sub>x</sub> that affected the calculation of atmospheric deposition from grazing. Updated NH<sub>3</sub> emissions as mentioned in 10.2.3.4 also contributed to a change in the indirect N<sub>2</sub>O emissions. The change in TAN factor for “heifers for breeding” described in 10.2.3.3 also contributed to a change in the 3D stage. The updated figures for the time series showed 2 per cent higher N<sub>2</sub>O emission from atmospheric deposition from managed soils as an average, from 1990 to 2020 compared to the previous submission.

### 10.2.3.8 3F Field burning of agricultural residues

Updated activity data for crop production in the year 2020 lead to approximately 5 per cent higher emissions for CH<sub>4</sub> and N<sub>2</sub>O for 2020 compared to earlier submission.

### 10.2.4 Land use, Land use change and Forestry

All emissions related to the Norwegian National Forest Inventory (NFI) estimated areas and living biomass are recalculated every year as well as for the 2023 submission. This is due to the interpolation and extrapolation method used to estimate the areas. Since NIR 2014, areas have been estimated using linear interpolation between the 1/5<sup>th</sup> of the NFI sample plots that are surveyed every year<sup>40</sup>. For any given year (after 1993) one fifth of the area and living biomass estimates are therefore based on measured sample plots, and four fifths of the estimates are based on interpolation or extrapolation in the final years. Extrapolation affects the four final reporting years and requires a recalculation of these years in the subsequent submissions.

There will therefore always be recalculation in the last few years of the time series. The area-related emissions are affected by this and comprise all C stock changes estimated for living biomass, litter, dead wood, DOM, mineral and organic soils (CRF Tables 4.A-4.F). In addition, the following non-CO<sub>2</sub> emission sources are also indirectly affected by the area estimates: CRF Table 4(II) Emissions and removals from drainage and rewetting of organic soils, and CRF Table 4(III) Direct N<sub>2</sub>O emissions from N mineralization/immobilization.

In addition to the interpolation and extrapolation method affecting area estimates, NFI sample plots are surveyed either in the field (if forested) or using aerial images. Corrections of previously attributed land-use categories that are not due to actual land-use changes therefore occur if new information becomes available. This can result in revised area estimates among all categories for the full time series.

For the NIR 2023 the whole time series was recalculated for all C emission sources and sinks due to the revised activity data (mainly areas and tree living biomass) and some minor methodological changes.

The largest recalculations occurred for the last four years (2017 – 2020) mainly due to extrapolation updates. However, recalculations have occurred throughout the time series due to changes in activity data and the methodologies. The most important methodological changes is the update in the climate methodology used with the Yasso07 model, which is

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<sup>40</sup> As of NIR2021, this method has been adapted slightly by performing the interpolation for each plot separately, and then aggregating to each NFI panel.

used for estimating litter, dead wood and mineral soil on forest land remaining forest land. Total changes in emissions (including non-CO<sub>2</sub> emissions) caused by recalculations for the LULUCF sector are shown in Figure 10-1.

Quantitatively, the largest changes in estimated C stock changes occurred for forest land. The estimated CO<sub>2</sub> uptake on forest land for the year 2020 was 1123 kt CO<sub>2</sub> eq smaller in the 2023 submission compared to the 2022 submission. The difference in total GHG removals from the LULUCF sector were 1166 kt CO<sub>2</sub> eq less in the 2023 NIR compared to the 2022 NIR submission for the recalculated year 2020 (Table 10.7).

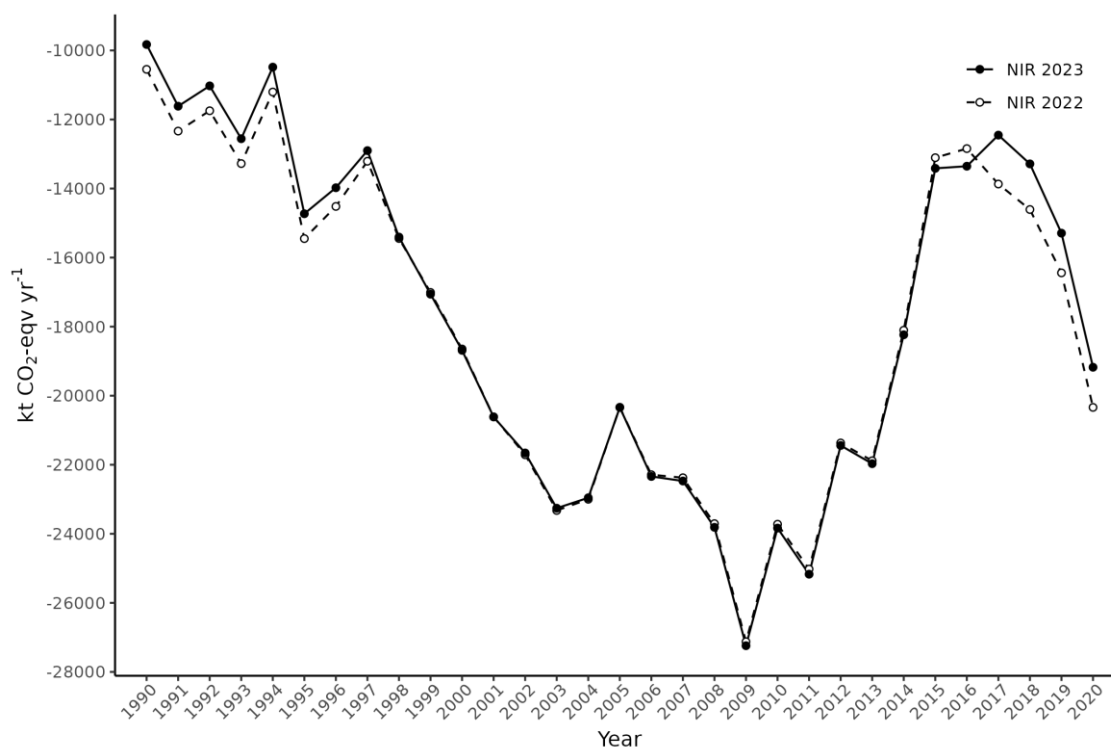


Figure 10-1 Recalculations illustrated for total emissions (kt CO<sub>2</sub> equivalents per year) estimated for the LULUCF sector in the 2023 submission compared to the 2022 submission.



| <b>Table 10-5 Recalculated GHG emissions (kt CO<sub>2</sub> equivalents yr<sup>-1</sup>) for 2020 per land-use category in the LULUCF sector.</b> |                                                                       |          |            |                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
|                                                                                                                                                   | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
| <b>Land-use category</b>                                                                                                                          | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>4.A Forest land</b>                                                                                                                            | -23394.2                                                              | -24517.2 | 1123.0     | decreased net removals  |
| <b>4.B Cropland</b>                                                                                                                               | 2289.5                                                                | 2245.7   | 43.7       | increased net emissions |
| <b>4.C Grassland</b>                                                                                                                              | 96.1                                                                  | 169.1    | -73.0      | decreased net emissions |
| <b>4.D Wetlands</b>                                                                                                                               | 401.8                                                                 | 306.3    | 95.5       | increased net emissions |
| <b>4.E Settlements</b>                                                                                                                            | 1877.1                                                                | 1900.0   | -22.9      | decreased net emissions |
| <b>4.F Other land</b>                                                                                                                             | 0.0                                                                   | 0.0      | 0.0        | no change               |
| <b>4.G HWP</b>                                                                                                                                    | -450.6                                                                | -449.3   | -1.4       | increased net removals  |
| <b>4(IV) Indirect N<sub>2</sub>O</b>                                                                                                              | 7.6                                                                   | 6.6      | 1.0        | increased net emissions |
| <b>Total sum</b>                                                                                                                                  | -19172.7                                                              | -20338.6 | 1166.0     | decreased net removals  |

The reasons for the recalculations within each land-use category and sink/source category and the effects for the last recalculated year of the inventory (2020) are described below.

#### **10.2.4.1 Forest Land**

##### **10.2.4.1.1 4A1 Forest land remaining forest land**

There has been a decrease in net removals of 1176.0 kt CO<sub>2</sub> (from -23658.4 kt CO<sub>2</sub> to -22482.4 kt CO<sub>2</sub>) for forest land remaining forest land.

| <b>Table 10-6 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for forest land remaining forest land. Ordered by descending absolute difference.</b> |                                                                       |          |            |                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
|                                                                                                                                                                                                             | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
| <b>Carbon pool</b>                                                                                                                                                                                          | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>living biomass</b>                                                                                                                                                                                       | -17575.7                                                              | -19178.1 | 1602.4     | decreased net removals  |
| <b>litter</b>                                                                                                                                                                                               | -5010.7                                                               | -4672.6  | -338.1     | increased net removals  |
| <b>dead wood</b>                                                                                                                                                                                            | -1013.2                                                               | -944.8   | -68.4      | increased net removals  |
| <b>organic soil</b>                                                                                                                                                                                         | 1233.9                                                                | 1245.9   | -12.0      | decreased net emissions |
| <b>mineral soil</b>                                                                                                                                                                                         | -116.7                                                                | -108.8   | -7.9       | increased net removals  |

- The large recalculation for living biomass occurs in the last years due to extrapolation update. The change is especially large for losses, in which recalculated emissions increased by 1079 kt CO<sub>2</sub> in 2020. This may be explained by the increase in harvest after 2009, reflected in the timber production statistics. The extrapolation is based on a linear trend for the last 10 years of each NFI panel. For panel 4, and 5 the trend is based on the years 2007 – 2017 and 2008 – 2018 respectively. As such the lower harvest levels prior to 2009, influence the projected losses for the last four years, potentially resulting in underestimation of losses, and further resulting in recalculations once more recent data is available. The recalculation also shows slightly reduced gains in living biomass of 523 kt CO<sub>2</sub> in 2020. It should be noted that gains and losses are inter-linked as removal of trees will result in fewer trees contributing to carbon sequestration. Hence an increase in losses also generally results in a reduction in gains.
- Litter, dead wood, and mineral soil have been recalculated for the whole time-series. The main reason for updates has been due to updates to the climate data used with Yasso07. The backward-looking moving-average for yearly climate variables applied to the methodology for forest land remaining forest land mineral soil, litter and dead wood, derived from the Yasso07 model, was updated. Previously each plot was applied a backward-looking 5-year moving-average for the yearly climate variables. The 5-years moving-average was used, because it matches the time interval of the NFI cycle. However, from 1986 until 1998, the first NFI cycle

varies from 1 to 12 year for different plots, due to change in the NFI observation design (see section 6.3.1). The current backward-looking moving-average methodology for the yearly climate variable, has a dynamic time period for the moving-average equal to the time interval of the NFI cycle specific for the plot and year of observation.

Another update is that the spin-up climate for the Yasso07 model, no longer uses a fixed 30-year period from 1960-1989. This is because new plots become forest land remaining forest land at different years during 1990 to current reporting year. The current methodology creates a spin-up climate for each plot equivalent to the last 30 years prior to the year the plot is defined as forest land remaining forest land. This ensures that mineral soil, litter and dead wood at equilibrium is set consistently 30 years from the reporting period.

Another update is the climate activity data. Each year there are minor version improvements to the SeNorge2018 gridded climate dataset from met.no. These are updates usually relate to addition or removal of meteorological stations, or bug fixes.

- Drained organic soil emissions have been recalculated for the entire time-series. This is due to updates to the registrations in the NFI database.

#### 10.2.4.1.2 4A2 Land converted to forest land

There has been an increase in net removals of -54.1 kt CO<sub>2</sub> (from -1073.2 kt CO<sub>2</sub> to -1127.3 kt CO<sub>2</sub>) for land converted to forest land.

**Table 10-7 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for land converted to forest land. Ordered by descending absolute difference.**

|                       | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|-----------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| <b>Carbon pool</b>    | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>living biomass</b> | -192.9                                                                | -155.3   | -37.5      | increased net removals  |
| <b>litter</b>         | -562.6                                                                | -554.4   | -8.2       | increased net removals  |
| <b>organic soil</b>   | 17.2                                                                  | 20.8     | -3.6       | decreased net emissions |
| <b>mineral soil</b>   | -19.2                                                                 | -15.9    | -3.3       | increased net removals  |
| <b>dead wood</b>      | -369.8                                                                | -368.5   | -1.4       | increased net removals  |

- For all sources changes occur in the last four years due to updated area extrapolation. Some reclassifications of the plots (whole and split) in the database occurs, which can cause recalculations for the whole timeseries.

### 10.2.4.2 Cropland

#### 10.2.4.2.1 4B1 Cropland remaining cropland

There has been a decrease in net emissions of -11.1 kt CO<sub>2</sub> (from 1643.0 kt CO<sub>2</sub> to 1631.9 kt CO<sub>2</sub>) for cropland remaining cropland.

**Table 10-8 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for cropland remaining cropland. Ordered by descending absolute difference.**

| Carbon pool         | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            | change description      |
|---------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
|                     | NIR 2023                                                              | NIR 2022 | difference |                         |
| organic soil        | 1683.8                                                                | 1696.9   | -13.1      | decreased net emissions |
| mineral soil        | -51.6                                                                 | -53.6    | 2.0        | decreased net removals  |
| living biomass      | -0.3                                                                  | -0.3     | 0.0        | increased net removals  |
| dead organic matter | 0.0                                                                   | 0.0      | 0.0        | no change               |

- CSC for cropland remaining cropland on mineral soil is calculated with reference to the carbon stock estimate 30 years before. Because we assume a C stock at equilibrium in 1989, the reference carbon stock of the 1989-2019 period is set to the C stock measured in 1989. From 2020 onward the reference carbon stock is then taken 30 years before. Therefore in 2020, 2021, 2022 the reference C stock would be respectively set in 1990, 1991, 1992, etc. The transition between a fixed reference year set in 1989, with a floating reference stock from 1990 onward was forgotten in previous submission. Its implementation in current submission led to a recalculation for the last two year.

- In addition, updated extrapolated area results in changes in mineral and organic soil emissions.

#### 10.2.4.2.2 4B2 Land converted to cropland

There has been an increase in net emissions of 55.5 kt CO<sub>2</sub> (from 496.5 kt CO<sub>2</sub> to 551.9 kt CO<sub>2</sub>) for land converted to cropland.

**Table 10-9 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for land converted to cropland. Ordered by descending absolute difference.**

|                            | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|----------------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| <b>Carbon pool</b>         | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>dead organic matter</b> | 282.0                                                                 | 229.4    | 52.6       | increased net emissions |
| <b>living biomass</b>      | 96.1                                                                  | 94.3     | 1.7        | increased net emissions |
| <b>mineral soil</b>        | 55.3                                                                  | 54.2     | 1.1        | increased net emissions |
| <b>organic soil</b>        | 118.5                                                                 | 118.5    | 0.0        | no change               |

- Dead organic matter, mineral soil and living biomass have changed for the last four common years due to updated extrapolation. The majority of the change comes from forest land to cropland conversions.

### 10.2.4.3 Grassland

#### 10.2.4.3.1 4C1 Grassland remaining grassland

There has been an increase in net removals of -17 kt CO<sub>2</sub> (from -266.7 kt CO<sub>2</sub> to -283.7 kt CO<sub>2</sub>) for grassland remaining grassland.

**Table 10-10 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for grassland remaining grassland. Ordered by descending absolute difference.**

|                    | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                    |
|--------------------|-----------------------------------------------------------------------|----------|------------|--------------------|
| <b>Carbon pool</b> | NIR 2023                                                              | NIR 2022 | difference | change description |

|                            |        |        |       |                         |
|----------------------------|--------|--------|-------|-------------------------|
| <b>living biomass</b>      | -388.9 | -369.7 | -19.2 | increased net removals  |
| <b>mineral soil</b>        | 32.6   | 30.5   | 2.2   | increased net emissions |
| <b>dead organic matter</b> | 0.0    | 0.0    | 0.0   | no change               |
| <b>organic soil</b>        | 72.6   | 72.6   | 0.0   | no change               |

- Tree living biomass estimates were updated for the whole time series due to updated area estimates and updated national emission factors for gains and losses.
- Similarly mineral soils emissions were updated for the whole time series due to updated mineral area estimates in the database. Additionally, rounding to 2 decimal places for the distribution of climate zone areas per soil type proves to have a significant impact on the emissions. In the current submission, the suppression of the rounding is responsible for the changes observed between the previous and current submission.

#### 10.2.4.3.2 4C2 Land converted to grassland

There has been a decrease in net emissions of -56.2 kt CO<sub>2</sub> (from 419.8 kt CO<sub>2</sub> to 363.6 kt CO<sub>2</sub>) for land converted to grassland.

**Table 10-11 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for land converted to grassland. Ordered by descending absolute difference.**

|                            | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|----------------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| <b>Carbon pool</b>         | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>dead organic matter</b> | 245.1                                                                 | 323.8    | -78.7      | decreased net emissions |
| <b>living biomass</b>      | 98.7                                                                  | 76.6     | 22.1       | increased net emissions |
| <b>organic soil</b>        | 29.7                                                                  | 29.0     | 0.7        | increased net emissions |
| <b>mineral soil</b>        | -9.9                                                                  | -9.6     | -0.3       | increased net removals  |

- Living biomass, dead organic matter, and mineral soil estimates were updated partly due to reclassifying the land-use class of a few plots in the database, and extrapolation. The majority of the recalculation comes from forest land to grassland.
- Cropland to grassland is a new land-use conversion and has resulted in emissions from drained organic soil from 2012 to the current reporting year.

#### 10.2.4.4 Wetlands

##### 10.2.4.4.1 4D1 Wetlands remaining wetlands

There has been an increase in net emissions 2.3 kt CO<sub>2</sub> (from 233.0 kt CO<sub>2</sub> to 235.3 kt CO<sub>2</sub>) for wetlands remaining wetlands.

**Table 10-12 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for wetlands remaining wetlands. Ordered by descending absolute.**

|                       | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|-----------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| <b>Carbon pool</b>    | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>organic soil</b>   | 311.4                                                                 | 304.5    | 6.9        | increased net emissions |
| <b>living biomass</b> | -76.1                                                                 | -71.5    | -4.6       | increased net removals  |

- Recalculation of living biomass and drained organic soil is due to changes in the activity data, and updated extrapolation for other wetlands remaining other wetlands.

##### 10.2.4.4.2 4D2 Land converted to wetlands

There has been an increase in net emissions of 91.1 kt CO<sub>2</sub> (from 34.2 kt CO<sub>2</sub> to 125.3 kt CO<sub>2</sub>) for land converted to wetlands.

**Table 10-13 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for land converted to wetlands. Ordered by descending absolute difference.**

|                    | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                    |
|--------------------|-----------------------------------------------------------------------|----------|------------|--------------------|
| <b>Carbon pool</b> | NIR 2023                                                              | NIR 2022 | difference | change description |

|                            |      |      |      |                         |
|----------------------------|------|------|------|-------------------------|
| <b>dead organic matter</b> | 82.2 | 21.3 | 60.9 | increased net emissions |
| <b>living biomass</b>      | 34.5 | 11.2 | 23.3 | increased net emissions |
| <b>organic soil</b>        | 8.6  | 1.7  | 6.9  | increased net emissions |
| <b>mineral soil</b>        | 0.0  | 0.0  | 0.0  | no change               |

- The recalculations for all estimates were due to updated extrapolation for the last four common years.

#### 10.2.4.5 Settlements

##### 10.2.4.5.1 4E1 Settlements remaining settlements

There has been an increase in net emissions of 23.8 kt CO<sub>2</sub> (from 143.4 kt CO<sub>2</sub> to 167.2 kt CO<sub>2</sub>) for settlements remaining settlements.

| <b>Table 10-14 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each carbon pool for settlements remaining settlements. Ordered by descending absolute difference.</b> |                                                                       |          |            |                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
|                                                                                                                                                                                                              | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
| <b>Carbon pool</b>                                                                                                                                                                                           | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>organic soil</b>                                                                                                                                                                                          | 167.2                                                                 | 143.4    | 23.8       | increased net emissions |
| <b>living biomass</b>                                                                                                                                                                                        | 0.0                                                                   | 0.0      | 0.0        | no change               |
| <b>dead organic matter</b>                                                                                                                                                                                   | 0.0                                                                   | 0.0      | 0.0        | no change               |
| <b>mineral soil</b>                                                                                                                                                                                          | 0.0                                                                   | 0.0      | 0.0        | no change               |

- Recalculations for organic soils were due to database updates and extrapolation.



#### 10.2.4.5.2 4E2 Land converted to settlements

There has been a decrease in net emissions of -53.1 kt CO<sub>2</sub> (from 1699.1 kt CO<sub>2</sub> to 1646.0 kt CO<sub>2</sub>) for land converted to settlements.

**Table 10-15 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr-1) for 2020 for each carbon pool for land converted to settlements. Ordered by descending absolute difference.**

|                            | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr-1) |          |            |                         |
|----------------------------|----------------------------------------------------------|----------|------------|-------------------------|
| <b>Carbon pool</b>         | NIR 2023                                                 | NIR 2022 | difference | change description      |
| <b>organic soil</b>        | 214.3                                                    | 131.1    | 83.1       | increased net emissions |
| <b>dead organic matter</b> | 846.9                                                    | 914.9    | -68.1      | decreased net emissions |
| <b>living biomass</b>      | 509.9                                                    | 574.9    | -65.0      | decreased net emissions |
| <b>mineral soil</b>        | 74.9                                                     | 78.1     | -3.2       | decreased net emissions |

- Organic soil emission estimates had the largest changes for lands converted to settlements. The main reason for the large change is due to a new observation in 2021 for cropland to settlements on organic soil, which causes changes in the estimates between 2016 and 2021 as a result of interpolation.
- All other carbon stock changes for the other carbon pools were mainly due to updated extrapolation. Some minor changes are due to updates in the database classification.

#### 10.2.4.6 Other Land

##### 10.2.4.6.1 4F1 Other land remaining other land

There have been no recalculations performed for this source category this year.

##### 10.2.4.6.2 4F2 Land converted to other land

There have been no recalculations performed for this source category this year.

#### 10.2.4.7 Harvested wood products

There has been an increase in net removals of -1.4 kt CO<sub>2</sub> (from -449.3 kt CO<sub>2</sub> to -450.6 kt CO<sub>2</sub>) for HWP.

| <b>Table 10-16 Recalculated CO<sub>2</sub> emissions (kt CO<sub>2</sub> yr<sup>-1</sup>) for 2020 for each HWP. Ordered by descending absolute difference.</b> |                                                                       |                 |                   |                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|-----------------|-------------------|---------------------------|
|                                                                                                                                                                | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |                 |                   |                           |
| <b>Carbon pool</b>                                                                                                                                             | <b>NIR 2023</b>                                                       | <b>NIR 2022</b> | <b>difference</b> | <b>change description</b> |
| <b>Domestic Wood-based panels</b>                                                                                                                              | 70.3                                                                  | 70.9            | -0.6              | decreased net emissions   |
| <b>Domestic Sawnwood</b>                                                                                                                                       | -193.2                                                                | -192.8          | -0.4              | increased net removals    |
| <b>Export Wood-based panels</b>                                                                                                                                | -25.9                                                                 | -25.6           | -0.4              | increased net removals    |
| <b>Export Sawnwood</b>                                                                                                                                         | -297.4                                                                | -297.4          | 0.0               | decreased net removals    |
| <b>Export Paper and paperboard</b>                                                                                                                             | 195.2                                                                 | 195.2           | 0.0               | increased net emissions   |
| <b>Domestic Paper and paperboard</b>                                                                                                                           | -199.6                                                                | -199.6          | 0.0               | increased net removals    |

Each year, when the new activity data are added from the FAO database, the activity data for the previous five years are checked and updated, if needed. The following activity data, which is used as data for inflow for 2020 were updated:

- Wood-based panels: production was 749 000 m<sup>3</sup> in NIR 2023 and 443 000 in NIR 2022m<sup>3</sup>), export was 429 750 m<sup>3</sup> in NIR 2023 and 215 032 m<sup>3</sup> in NIR 2022), domestic consumption was 319 250 m<sup>3</sup> in NIR 2023 and 227 968 m<sup>3</sup> in NIR 2022).
- Change in the FAOSTAT activity data for wood-based panels in 2022. The timeseries back to 1961 was changed by FAOSTAT, import and export was slightly reduced up to 2015. For 2017 to 2020 the production volumes were significantly increased, for 2020 from 443 000 m<sup>3</sup> to 749 000 m<sup>3</sup>. In the same period import (not accounted) and export also increased, in 2020 export increased from 215 032 m<sup>3</sup> to 429 750 m<sup>3</sup>.

#### 10.2.4.8 4 (I) Direct N<sub>2</sub>O emission from managed soils

There has been an increase in net emissions of 3.7 kt CO<sub>2</sub> eq (from 7.9 kt CO<sub>2</sub> eq to 11.6 kt CO<sub>2</sub> eq) for N<sub>2</sub>O from fertilized soils.

| <b>Table 10-17 Recalculated non-CO<sub>2</sub> GHG emissions (kt CO<sub>2</sub> eq yr<sup>-1</sup>) for 2020 for fertilized land uses. Ordered by descending absolute difference.</b> |                         |                  |                                                                       |          |            |                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
|                                                                                                                                                                                       |                         |                  | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
| <b>Land-use change</b>                                                                                                                                                                | source                  | GHG              | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>Forest land remaining forest land</b>                                                                                                                                              | Inorganic N fertilizers | N <sub>2</sub> O | 5.39805                                                               | 1.71774  | 3.68031    | increased net emissions |
| <b>Settlements remaining Settlements</b>                                                                                                                                              | Organic N fertilizers   | N <sub>2</sub> O | 6.19835                                                               | 6.19834  | 0.00001    |                         |

- N<sub>2</sub>O emission from direct forest fertilization was erroneously given as N-N<sub>2</sub>O emission. Correction induced a general increase of the estimates by a factor of 3.14 (i.e. 44/14).

#### 10.2.4.9 4 (II) Emissions and removal from drainage of organic soils

There has been an increase in net emissions of 5.1 kt CO<sub>2</sub> eq (from 411.3 kt CO<sub>2</sub> eq to 416.4 kt CO<sub>2</sub> eq) for drained organic soil non-CO<sub>2</sub> GHG.

**Table 10-18 Recalculated non-CO<sub>2</sub> GHG emissions (kt CO<sub>2</sub> eq yr<sup>-1</sup>) for 2020 for drained organic soil. Ordered by descending absolute difference.**

|             |                  | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|-------------|------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| Land use    | GHG              | NIR 2023                                                              | NIR 2022 | difference | change description      |
| Settlements | N <sub>2</sub> O | 22.9                                                                  | 18.0     | 4.8        | increased net emissions |
| Forest land | N <sub>2</sub> O | 153.0                                                                 | 154.9    | -1.9       | decreased net emissions |
| Wetlands    | N <sub>2</sub> O | 31.1                                                                  | 29.5     | 1.7        | increased net emissions |
| Settlements | CH <sub>4</sub>  | 27.6                                                                  | 26.2     | 1.4        | increased net emissions |
| Cropland    | CH <sub>4</sub>  | 101.5                                                                 | 102.2    | -0.7       | decreased net emissions |
| Forest land | CH <sub>4</sub>  | 56.5                                                                  | 57.2     | -0.7       | decreased net emissions |
| Wetlands    | CH <sub>4</sub>  | 10.1                                                                  | 9.6      | 0.4        | increased net emissions |
| Grassland   | CH <sub>4</sub>  | 13.8                                                                  | 13.7     | 0.1        | increased net emissions |

- All observed changes were contributed by updates in the NFI database and extrapolation.

#### 10.2.4.10 4(III) Direct N<sub>2</sub>O emissions from N mineralization and immobilisation

There has been an increase in net emissions of 0.39 kt CO<sub>2</sub> eq (from 13.75 kt CO<sub>2</sub> eq to 14.14 kt CO<sub>2</sub> eq) for direct N<sub>2</sub>O emissions.

**Table 10-19 Recalculated direct N<sub>2</sub>O emissions (kt CO<sub>2</sub> eq yr<sup>-1</sup>) from N mineralization/immobilization for 2020. Ordered by descending absolute difference.**

|                                 |  | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|---------------------------------|--|-----------------------------------------------------------------------|----------|------------|-------------------------|
| Land-use change                 |  | NIR 2023                                                              | NIR 2022 | difference | change description      |
| Lands converted to settlements  |  | 7.31                                                                  | 7.14     | 0.17       | increased net emissions |
| Grasslands remaining grasslands |  | 2.47                                                                  | 2.31     | 0.16       | increased net emissions |

|                                       |      |      |       |                         |
|---------------------------------------|------|------|-------|-------------------------|
| <b>Lands converted to cropland</b>    | 4.19 | 4.11 | 0.08  | increased net emissions |
| <b>Lands converted to forest land</b> | 0.17 | 0.19 | -0.02 | decreased net emissions |

- All observed changes were mainly due to updates of the NFI area and extrapolation.
- Additionally, the change in the rounding of decimals for grassland remaining grassland will resulting changes also for N<sub>2</sub>O emissions from N-mineralization/immobilization.

#### 10.2.4.11 4(IV) Indirect N<sub>2</sub>O emissions from managed soils

There has been an increase in net emissions of 1.0 kt CO<sub>2</sub> eq (from 6.6 kt CO<sub>2</sub> eq to 7.6 kt CO<sub>2</sub> eq) for indirect N<sub>2</sub>O emissions.

**Table 10-20 Recalculated indirect N<sub>2</sub>O emissions (kt CO<sub>2</sub> eq yr<sup>-1</sup>) for 2020. Ordered by descending absolute difference.**

|                                      | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|--------------------------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| <b>Source</b>                        | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>Nitrogen leaching and run-off</b> | 5.8                                                                   | 5.1      | 0.7        | increased net emissions |
| <b>Atmospheric deposition</b>        | 1.8                                                                   | 1.5      | 0.3        | increased net emissions |

- All observed changes were due to updates in 4(I) and 4(III), which are used as input data for the calculations of indirect N<sub>2</sub>O emissions.

#### 10.2.4.12 4(V) Biomass burning

There has been a slight increase in net emissions of 0.0002 kt CO<sub>2</sub> eq (from 0.4159 kt CO<sub>2</sub> eq to 0.4161 kt CO<sub>2</sub> eq) for forest land wildfires.

**Table 10-21 Recalculated non-CO<sub>2</sub> GHG emissions (kt CO<sub>2</sub> eq yr<sup>-1</sup>) for 2020 forest land wildfires. Ordered by descending absolute difference.**

|                       | Emissions for 2020 (kt CO <sub>2</sub> equivalents yr <sup>-1</sup> ) |          |            |                         |
|-----------------------|-----------------------------------------------------------------------|----------|------------|-------------------------|
| <b>GHG</b>            | NIR 2023                                                              | NIR 2022 | difference | change description      |
| <b>N<sub>2</sub>O</b> | 0.14310                                                               | 0.14292  | 0.00018    | increased net emissions |
| <b>CH<sub>4</sub></b> | 0.27300                                                               | 0.27298  | 0.00002    | increased net emissions |

- This source was recalculated due to updated data on estimated forest areas affected by wildfire.

## 10.2.5 Waste

### 10.2.5.1 5A1A Anaerobic managed waste disposal sites

- Revised activity data. Activity data for the previous year, 2020, have been updated because the Norwegian waste accounts has not released updated figures in time for the emission inventory calculations. The updated activity data did not lead to any difference in the CH<sub>4</sub> emissions.
- Revised activity data. The amounts of recovered landfill gas have been updated in the period of 2017-2020. The impact of the update is a total reduction in emission of 548 tonnes over the four years. The highest reduction was in 2019 where the recovery increased by 524 tonnes, equal to an increase of 8 per cent in recovery compared to the 2022 submission.
- Revised methodology. There has been a decline in the NMVOC emission due to a change of data source. Previously it was assumed that the NMVOC was aligned with the total amount of CH<sub>4</sub> from a landfill site. In the updated calculation the activity data is changed to total amount of CH<sub>4</sub>, corrected for the amount recovered. The reason is that the amounts of NMVOC should be in line with the amounts of CH<sub>4</sub> emitted, not the amounts of CH<sub>4</sub> in total. The changes are given in [Table10-22](#) below.

| Table10-22 Effects of new data source for NMVOC calculations |                           |                 |        |
|--------------------------------------------------------------|---------------------------|-----------------|--------|
|                                                              | Emission of NMVOC, tonnes |                 | Change |
|                                                              | 2022 submission           | 2023 submission | %      |
| <b>1990</b>                                                  | 1 219                     | 1 086           | -10.9  |
| <b>1991</b>                                                  | 1 234                     | 1 035           | -16.1  |
| <b>1992</b>                                                  | 1 244                     | 1 019           | -18.1  |
| <b>1993</b>                                                  | 1 250                     | 1 023           | -18.1  |
| <b>1994</b>                                                  | 1 251                     | 1 020           | -18.5  |
| <b>1995</b>                                                  | 1 249                     | 1 026           | -17.8  |
| <b>1996</b>                                                  | 1 244                     | 984             | -20.9  |
| <b>1997</b>                                                  | 1 236                     | 962             | -22.2  |
| <b>1998</b>                                                  | 1 227                     | 877             | -28.5  |
| <b>1999</b>                                                  | 1 218                     | 834             | -31.6  |
| <b>2000</b>                                                  | 1 205                     | 861             | -28.5  |

|             |       |     |       |
|-------------|-------|-----|-------|
| <b>2001</b> | 1 188 | 825 | -30.5 |
| <b>2002</b> | 1 165 | 786 | -32.5 |
| <b>2003</b> | 1 144 | 777 | -32.1 |
| <b>2004</b> | 1 123 | 770 | -31.4 |
| <b>2005</b> | 1 106 | 724 | -34.5 |
| <b>2006</b> | 1 086 | 734 | -32.5 |
| <b>2007</b> | 1 071 | 718 | -33.0 |
| <b>2008</b> | 1 059 | 686 | -35.2 |
| <b>2009</b> | 1 043 | 694 | -33.5 |
| <b>2010</b> | 1 012 | 680 | -32.8 |
| <b>2011</b> | 964   | 672 | -30.2 |
| <b>2012</b> | 910   | 650 | -28.6 |
| <b>2013</b> | 854   | 631 | -26.1 |
| <b>2014</b> | 803   | 616 | -23.2 |
| <b>2015</b> | 756   | 581 | -23.2 |
| <b>2016</b> | 714   | 547 | -23.3 |
| <b>2017</b> | 674   | 516 | -23.5 |
| <b>2018</b> | 639   | 496 | -22.5 |
| <b>2019</b> | 606   | 468 | -22.7 |
| <b>2020</b> | 574   | 444 | -22.7 |

#### **10.2.5.2 5B1A Composting facilities, Municipal solid waste**

- Revised activity data. Activity data for the previous year, 2020, have been updated because the Norwegian waste accounts has not released updated figures in time for the emission inventory calculations. The update led to an increase of emissions from N<sub>2</sub>O and CH<sub>4</sub> by 6.1 per cent in 2020 compared to the 2022 submission.

#### **10.2.5.3 5B1B Home composting**

- Revised activity data. Activity data was revised for 2019 and 2020 due to updated information on the amounts of household waste per inhabitant. The update led to a decrease of CH<sub>4</sub> emissions by 0.7 per cent in 2019 and an increase by 2.8 per cent in 2020 compared to the 2022 submission.

- Correction of error. There was also a correction in the emissions in the period of 1990-2008 due to an error in the calculation. The effects of the recalculation are given in [Table10-23](#) below.

| <b>Table10-23 Effects of recalculation in 5B1b, home composting. 1990-2008. Change compared to 2022 submission.</b> |                 |                  |                                      |
|---------------------------------------------------------------------------------------------------------------------|-----------------|------------------|--------------------------------------|
|                                                                                                                     | Change in kg    |                  | Change in %                          |
|                                                                                                                     | CH <sub>4</sub> | N <sub>2</sub> O | CH <sub>4</sub> and N <sub>2</sub> O |
| <b>1990</b>                                                                                                         | -354            | -21              | -1.1                                 |
| <b>1991</b>                                                                                                         | -354            | -21              | -1.1                                 |
| <b>1992</b>                                                                                                         | -356            | -21              | -1.1                                 |
| <b>1993</b>                                                                                                         | -377            | -23              | -1.0                                 |
| <b>1994</b>                                                                                                         | -398            | -24              | -1.0                                 |
| <b>1995</b>                                                                                                         | -419            | -25              | -1.0                                 |
| <b>1996</b>                                                                                                         | -409            | -25              | -1.0                                 |
| <b>1997</b>                                                                                                         | -425            | -26              | -1.0                                 |
| <b>1998</b>                                                                                                         | -450            | -27              | -1.0                                 |
| <b>1999</b>                                                                                                         | -476            | -29              | -1.0                                 |
| <b>2000</b>                                                                                                         | -491            | -29              | -1.0                                 |
| <b>2001</b>                                                                                                         | -322            | -19              | -0.6                                 |
| <b>2002</b>                                                                                                         | -338            | -20              | -0.6                                 |
| <b>2003</b>                                                                                                         | -339            | -20              | -0.6                                 |
| <b>2004</b>                                                                                                         | -348            | -21              | -0.6                                 |
| <b>2005</b>                                                                                                         | -802            | -48              | -1.3                                 |
| <b>2006</b>                                                                                                         | -874            | -52              | -1.4                                 |
| <b>2007</b>                                                                                                         | -1244           | -75              | -1.9                                 |
| <b>2008</b>                                                                                                         | -1159           | -70              | -1.8                                 |

#### 10.2.5.4 5B2A biogas facilities, composting facilities

- Activity data for the previous year, 2020, have been updated because the Norwegian waste accounts has not released updated figures in time for the emission inventory calculations. The updated waste amounts led to an increase in emissions of 12.2 per cent in 2020 compared to the 2022 submission.
- Revised activity data. Activity data was updated for 2018 and 2019 due to new information from one facility. The updated figures led to a decrease in the CH<sub>4</sub> emissions by 1.4 per cent in 2018 and 3.7 per cent in 2019 compared to the 2022 submission.

#### 10.2.5.5 5C11a Municipal biogenic waste incineration

- Correction of error. The emissions of NMVOC in 2012 are removed as this emission is found to be an error in the reported figures. The reduction is 0.1 tons NMVOC.
- There have been adjustments in the activity data in the period of 2010-2020, leading to relatively high percentage changes due to low emissions of N<sub>2</sub>O and CH<sub>4</sub>. Total change in the emissions for N<sub>2</sub>O and CH<sub>4</sub> were a reduction of 3.9 and 28 tonnes respectively. The total reduction in CO<sub>2</sub> emissions was 99.2 ktonnes.

The recalculations have led to changes in the period as shown in Table 10.24 below, compared to the 2022 submission.

| Table 10-24 Effects of recalculations in 5C11a, changes from previous submission |                 |                   |                 |                   |                  |                   |
|----------------------------------------------------------------------------------|-----------------|-------------------|-----------------|-------------------|------------------|-------------------|
|                                                                                  | CO <sub>2</sub> |                   | CH <sub>4</sub> |                   | N <sub>2</sub> O |                   |
|                                                                                  | Change in ktons | Percentage change | Change in tons  | Percentage change | Change in tons   | Percentage change |
| <b>2010</b>                                                                      | -6.6            | -19.3             | -1.8            | -32.5             | -0.2             | -94.1             |
| <b>2011</b>                                                                      | -17.7           | -42.9             | -4.8            | -60.2             | -0.6             | -98.0             |
| <b>2014</b>                                                                      | -10.0           | -42.8             | -0,6            | -60,1             | -0.4             | -98.0             |
| <b>2015</b>                                                                      | -6.9            | -23.1             | -2,7            | -37.7             | -0.3             | -95.2             |
| <b>2016</b>                                                                      | -10.1           | -34.1             | -1,8            | -51.0             | -0.4             | -97.2             |
| <b>2017</b>                                                                      | -12.1           | -35.2             | -2,7            | -52.3             | -0.4             | -97.3             |
| <b>2018</b>                                                                      | -9.9            | -31.4             | -3.3            | -51.9             | -0.5             | -97.6             |
| <b>2019</b>                                                                      | -13.4           | -40.3             | -3.7            | -58.3             | -0.5             | -97.9             |
| <b>2020</b>                                                                      | -12.5           | -36.1             | -4.0            | -57.1             | -0.6             | -98.0             |



**10.2.5.6 5C11b1 Other, industrial waste**

- Revised activity data. There has been a correction in the reported amounts of flared biogas from one facility in 2019. The correction led to a reduction in the emissions of CH<sub>4</sub> and N<sub>2</sub>O compared to the 2022 submission.

**10.2.5.7 5C12A Incineration of Municipal solid waste**

- Correction of error. An error in the previous calculation changed the emission factor. The calculation is updated with the correct emission factors in the present submission. The error was for the whole time series.
- Reallocation. The activity data in 5.C.1.2 have been updated due to a reallocation from 1A1A. This reallocation is made due to a quality check to secure the correct distribution of waste burned with and without energy utilization. The result is an increase in emissions throughout the period 2003-2020.

Details on the recalculations in 5C12a are given in [Table10-25](#) below.

| <b>Table10-25 Effects of recalculations in 5C12A.<br/>Percentage change and change in ktonnes for incinerated waste and CO<sub>2</sub></b> |                           |   |                                   |       |
|--------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|---|-----------------------------------|-------|
|                                                                                                                                            | Incinerated waste, change |   | CO <sub>2</sub> emissions, Change |       |
|                                                                                                                                            | ktonnes                   | % | ktonnes                           | %     |
| <b>1990</b>                                                                                                                                | 0                         | 0 | -1.7                              | -11.3 |
| <b>1991</b>                                                                                                                                | 0                         | 0 | -2.6                              | -11.3 |
| <b>1992</b>                                                                                                                                | 0                         | 0 | -2.5                              | -11.3 |
| <b>1993</b>                                                                                                                                | 0                         | 0 | -3.2                              | -11.3 |
| <b>1994</b>                                                                                                                                | 0                         | 0 | -2.6                              | -10.7 |
| <b>1995</b>                                                                                                                                | 0                         | 0 | -2.5                              | -11.0 |
| <b>1996</b>                                                                                                                                | 0                         | 0 | -2.6                              | -10.3 |
| <b>1997</b>                                                                                                                                | 0                         | 0 | -2.5                              | -9.7  |
| <b>1998</b>                                                                                                                                | 0                         | 0 | -2.5                              | -9.1  |
| <b>1999</b>                                                                                                                                | 0                         | 0 | -3.7                              | -8.5  |

|      |     |     |      |       |
|------|-----|-----|------|-------|
| 2000 | 0   | 0   | -6.9 | -7.9  |
| 2001 | 0   | 0   | -7.0 | -7.2  |
| 2002 | 0   | 0   | -6.2 | -6.5  |
| 2003 | 65  | 54  | 29.8 | 45.3  |
| 2004 | 63  | 45  | 28.8 | 38.0  |
| 2005 | 68  | 50  | 32.4 | 43.2  |
| 2006 | 77  | 61  | 38.3 | 54.8  |
| 2007 | 79  | 60  | 39.8 | 55.3  |
| 2008 | 82  | 67  | 42.4 | 63.2  |
| 2009 | 80  | 231 | 42.8 | 226.5 |
| 2010 | 133 | 59  | 71.9 | 57.7  |
| 2011 | 171 | 56  | 93.9 | 55.6  |
| 2012 | 136 | 49  | 76.3 | 50.5  |
| 2013 | 173 | 64  | 95.0 | 64.5  |
| 2014 | 124 | 33  | 68.3 | 33.5  |
| 2015 | 132 | 41  | 72.5 | 41.2  |
| 2016 | 97  | 28  | 53.3 | 28.4  |
| 2017 | 137 | 39  | 75.3 | 39.1  |
| 2018 | 101 | 27  | 55.5 | 27.1  |
| 2019 | 121 | 42  | 66.4 | 41.8  |
| 2020 | 148 | 51  | 81.4 | 50.6  |

#### 10.2.5.8 5D1 Domestic wastewater

- Revised activity data. There has been an update of the activity data in 2020, leading to a minor reduction of CH<sub>4</sub> and an increase of NMVOC emissions. The changes are – 0,8 per cent for CH<sub>4</sub> and 1.6 percent for NMVOC compared to the previous submission.
- Correction of error. A double count in connection to the activity data for Nitrogen content in wastewater has been identified and removed. The correction led to a

reduction in N<sub>2</sub>O emissions in the whole timeseries. Changes are described in Table10-26.

| <b>Table10-26 Effect of recalculation of N<sub>2</sub>O emission in 5D1.<br/>Percentage change and change in tonnes for N<sub>2</sub>O</b> |                 |                   |
|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------------------|
|                                                                                                                                            | change in tonne | percentage change |
| 1990                                                                                                                                       | -15.45          | -10.3             |
| 1991                                                                                                                                       | -15.74          | -10.5             |
| 1992                                                                                                                                       | -16.02          | -10.7             |
| 1993                                                                                                                                       | -16.30          | -10.9             |
| 1994                                                                                                                                       | -24.45          | -14.4             |
| 1995                                                                                                                                       | -24.73          | -14.3             |
| 1996                                                                                                                                       | -32.23          | -18.7             |
| 1997                                                                                                                                       | -31.88          | -18.0             |
| 1998                                                                                                                                       | -19.08          | -10.6             |
| 1999                                                                                                                                       | -25.98          | -14.2             |
| 2000                                                                                                                                       | -4.92           | -3.1              |
| 2001                                                                                                                                       | -35.29          | -20.2             |
| 2002                                                                                                                                       | -36.12          | -21.3             |
| 2003                                                                                                                                       | -40.33          | -23.1             |
| 2004                                                                                                                                       | -44.66          | -24.9             |
| 2005                                                                                                                                       | -46.62          | -25.5             |
| 2006                                                                                                                                       | -41.33          | -22.4             |
| 2007                                                                                                                                       | -48.18          | -25.1             |
| 2008                                                                                                                                       | -51.25          | -26.2             |
| 2009                                                                                                                                       | -51.97          | -25.6             |
| 2010                                                                                                                                       | -52.45          | -26.1             |
| 2011                                                                                                                                       | -55.12          | -26.8             |
| 2012                                                                                                                                       | -58.80          | -28.0             |

|             |        |       |
|-------------|--------|-------|
| <b>2013</b> | -55.98 | -26.7 |
| <b>2014</b> | -60.12 | -27.8 |
| <b>2015</b> | -65.02 | -28.7 |
| <b>2016</b> | -62.19 | -27.5 |
| <b>2017</b> | -65.11 | -27.8 |
| <b>2018</b> | -65.75 | -28.8 |
| <b>2019</b> | -60.49 | -26.8 |
| <b>2020</b> | -61.55 | -26.5 |

#### 10.2.5.9 5D2 Industrial Wastewater

- Revised activity data. Activity data was updated in the period of 1990-2020. These changes were made to ensure that the data was processed uniformly throughout the time series and assure that it also is processed in the same way in the years to come. The update led to changes in the emissions of CH<sub>4</sub> as given in Table10-27 below. The emissions of NMVOC are considered to be insignificant.
- Revised activity data. There are reduced emissions of N<sub>2</sub>O in the whole time series. The reduction is due to a change in the population of industry units included in the calculation. Details on the changes can be found in Table10-27

**Table10-27 Effects of recalculations in 5D2, changes from previous submission**

|             | CH <sub>4</sub> |                   | N <sub>2</sub> O |                   |
|-------------|-----------------|-------------------|------------------|-------------------|
|             | Change in tons  | Percentage change | Change in tons   | Percentage change |
| <b>1990</b> | -0.9            | 0.0               | -2.5             | -43.0             |
| <b>1991</b> | -1.6            | -0.1              | -3.1             | -49.1             |
| <b>1992</b> | -48.4           | -1.3              | -1.4             | -34.7             |
| <b>1993</b> | -2.3            | -0.1              | -4.1             | -59.3             |
| <b>1994</b> | -1.7            | -0.1              | -6.6             | -59.3             |
| <b>1995</b> | -1.0            | 0.0               | -7.4             | -60.0             |
| <b>1996</b> | -1.7            | -0.1              | -7.0             | -56.4             |

|      |       |      |      |       |
|------|-------|------|------|-------|
| 1997 | -8.6  | -0.3 | -5.6 | -53.7 |
| 1998 | -4.1  | -0.2 | -6.0 | -59.4 |
| 1999 | 0.0   | 0.0  | -5.5 | -56.4 |
| 2000 | -0.4  | 0.0  | -4.3 | -41.9 |
| 2001 | 14.9  | 0.7  | -5.2 | -47.4 |
| 2002 | -34.9 | -1.7 | -5.5 | -45.4 |
| 2003 | -8.6  | -0.4 | -3.4 | -38.3 |
| 2004 | 96.2  | 4.6  | -4.5 | -41.2 |
| 2005 | 18.3  | 0.9  | -3.6 | -39.5 |
| 2006 | 32.5  | 1.6  | -2.7 | -30.7 |
| 2007 | 24.0  | 1.2  | -2.5 | -31.4 |
| 2008 | 23.3  | 1.2  | -2.3 | -29.2 |
| 2009 | -9.1  | -0.5 | -1.5 | -20.7 |
| 2010 | -9.7  | -0.5 | -4.4 | -40.5 |
| 2011 | -4.4  | -0.2 | -1.9 | -21.1 |
| 2012 | -23.2 | -1.3 | -1.4 | -18.0 |
| 2013 | -31.9 | -2.1 | 1.5  | 22.2  |
| 2014 | -34.5 | -2.6 | -1.5 | -18.5 |
| 2015 | -9.0  | -0.7 | -1.5 | -17.8 |
| 2016 | -5.6  | -0.4 | -1.3 | -15.0 |
| 2017 | 3.0   | 0.2  | -1.4 | -15.8 |
| 2018 | 22.7  | 1.7  | -2.2 | -22.2 |
| 2019 | 13.6  | 1.1  | -2.7 | -28.2 |
| 2020 | -5.4  | -0.4 | -0.6 | -8.7  |

## 10.3 Implications for emissions levels and trends, including time-series consistency

### 10.3.1 Implications for emission levels

In 2023, the emission inventory has been recalculated using GWPs from AR5, rather than AR4. Also, indirect emissions of CO<sub>2</sub> are now excluded from sectoral totals, and reported separately in CRF tables summary 2, 6 and 10. An assessment of implication of these recalculations at a detailed level is not feasible.

Table 10-28 show the effects of recalculations on the total emission figures for CO<sub>2</sub>-equivalents for the period 1990-2020. The new GWP values is the single most important reason for changes in the emission estimates, and the impact from these have therefore been isolated in the tables.

| Table 10-28 Implications of recalculations for total emissions (including and excluding LULUCF) |                                                 |                                              |                                                            |                                                                         |                                                 |                                              |                                                            |                                                                         |
|-------------------------------------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------------|
| Year                                                                                            | Excluding LULUCF                                |                                              |                                                            |                                                                         | Including LULUCF                                |                                              |                                                            |                                                                         |
|                                                                                                 | 2022 Resubmission (kt CO <sub>2</sub> -eq. AR4) | 2023 Submission (kt CO <sub>2</sub> eq. AR5) | Impact of GWP change <sup>1</sup> (kt CO <sub>2</sub> eq.) | Difference without GWP impact <sup>2</sup> (kt CO <sub>2</sub> eq. AR5) | 2022 Resubmission (kt CO <sub>2</sub> -eq. AR4) | 2023 Submission (kt CO <sub>2</sub> eq. AR5) | Impact of GWP change <sup>1</sup> (kt CO <sub>2</sub> eq.) | Difference without GWP impact <sup>1</sup> (kt CO <sub>2</sub> eq. AR5) |
| 1990                                                                                            | 51 432                                          | 51 305                                       | -37                                                        | -90                                                                     | 40 890                                          | 41 477                                       | -43                                                        | 630                                                                     |
| 1991                                                                                            | 49 025                                          | 48 955                                       | 5                                                          | -74                                                                     | 36 695                                          | 37 339                                       | -2                                                         | 646                                                                     |
| 1992                                                                                            | 47 368                                          | 47 419                                       | 116                                                        | -65                                                                     | 35 627                                          | 36 393                                       | 110                                                        | 656                                                                     |
| 1993                                                                                            | 49 332                                          | 49 378                                       | 108                                                        | -62                                                                     | 36 061                                          | 36 821                                       | 102                                                        | 659                                                                     |
| 1994                                                                                            | 51 236                                          | 51 330                                       | 145                                                        | -51                                                                     | 40 038                                          | 40 847                                       | 138                                                        | 670                                                                     |
| 1995                                                                                            | 51 631                                          | 51 717                                       | 136                                                        | -50                                                                     | 36 188                                          | 36 987                                       | 130                                                        | 670                                                                     |
| 1996                                                                                            | 54 511                                          | 54 617                                       | 154                                                        | -49                                                                     | 40 000                                          | 40 640                                       | 148                                                        | 493                                                                     |
| 1997                                                                                            | 54 533                                          | 54 606                                       | 179                                                        | -105                                                                    | 41 330                                          | 41 705                                       | 172                                                        | 203                                                                     |
| 1998                                                                                            | 54 561                                          | 54 672                                       | 159                                                        | -48                                                                     | 39 121                                          | 39 266                                       | 153                                                        | -8                                                                      |
| 1999                                                                                            | 55 583                                          | 55 683                                       | 145                                                        | -45                                                                     | 38 580                                          | 38 623                                       | 138                                                        | -95                                                                     |
| 2000                                                                                            | 54 922                                          | 55 070                                       | 179                                                        | -31                                                                     | 36 281                                          | 36 384                                       | 172                                                        | -70                                                                     |
| 2001                                                                                            | 56 193                                          | 56 339                                       | 178                                                        | -32                                                                     | 35 586                                          | 35 724                                       | 172                                                        | -34                                                                     |
| 2002                                                                                            | 55 010                                          | 55 078                                       | 107                                                        | -39                                                                     | 33 306                                          | 33 419                                       | 100                                                        | 13                                                                      |

|             |        |        |     |      |        |        |     |       |
|-------------|--------|--------|-----|------|--------|--------|-----|-------|
| <b>2003</b> | 55 613 | 55 717 | 179 | -75  | 32 296 | 32 459 | 173 | -10   |
| <b>2004</b> | 56 014 | 56 101 | 153 | -66  | 33 020 | 33 144 | 146 | -22   |
| <b>2005</b> | 54 945 | 55 003 | 131 | -73  | 34 616 | 34 663 | 124 | -77   |
| <b>2006</b> | 54 934 | 55 015 | 153 | -72  | 32 651 | 32 676 | 147 | -121  |
| <b>2007</b> | 56 605 | 56 712 | 167 | -60  | 34 235 | 34 242 | 161 | -154  |
| <b>2008</b> | 55 131 | 55 232 | 200 | -100 | 31 432 | 31 420 | 194 | -206  |
| <b>2009</b> | 52 672 | 52 855 | 307 | -124 | 25 553 | 25 614 | 300 | -240  |
| <b>2010</b> | 54 939 | 55 233 | 335 | -41  | 31 223 | 31 399 | 328 | -152  |
| <b>2011</b> | 53 991 | 54 289 | 314 | -16  | 28 976 | 29 119 | 308 | -165  |
| <b>2012</b> | 53 413 | 53 671 | 303 | -44  | 32 050 | 32 259 | 296 | -87   |
| <b>2013</b> | 53 672 | 53 916 | 296 | -51  | 31 794 | 31 976 | 289 | -107  |
| <b>2014</b> | 54 041 | 54 246 | 284 | -78  | 35 943 | 36 040 | 278 | -180  |
| <b>2015</b> | 54 488 | 54 691 | 282 | -80  | 41 387 | 41 308 | 276 | -355  |
| <b>2016</b> | 53 586 | 53 765 | 274 | -94  | 40 749 | 40 446 | 267 | -570  |
| <b>2017</b> | 52 840 | 52 981 | 266 | -126 | 38 978 | 40 532 | 259 | 1 295 |
| <b>2018</b> | 52 871 | 53 001 | 257 | -127 | 38 270 | 39 719 | 251 | 1 198 |
| <b>2019</b> | 51 086 | 51 219 | 229 | -96  | 34 650 | 35 930 | 223 | 1 057 |
| <b>2020</b> | 49 273 | 49 498 | 236 | -11  | 28 940 | 30 325 | 229 | 1 155 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5

The overall impact of recalculations *without* the LULUCF sector, was minor, adding up to a reduction of 0.24 per cent (127 ktonnes CO<sub>2</sub> equivalents) in 1990 and an increase of 0.46 per cent (225 ktonnes) in 2020.

Recalculations in the LULUCF sector also resulted in changes in the total level of greenhouse gas emissions *with* LULUCF for all years in the time series. According to the most recent estimates, the emissions in 1990 were 1.4 per cent higher (about 587 ktonnes CO<sub>2</sub> equivalents) than in the previous submission and about 4.8 per cent higher (1 385 ktonnes) in 2020, due to reduced uptake. See section 10.2.4 for more information on the recalculations in the LULUCF-sector.

Table 10-29, Table 10-30, Table 10-31, Table 10-32, Table 10-33 and Table 10-34, show the effects of recalculations on the total emission figures for CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>

for the period 1990-2020. The impact from the new GWP values have been isolated in the tables.

**Table 10-29 Implications of recalculations for CO<sub>2</sub> emissions (including and excluding LULUCF)**

|      | Excluding LULUCF                                |                                              |                                                                         | Including LULUCF                                |                                              |                                                                         |
|------|-------------------------------------------------|----------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------|-------------------------------------------------------------------------|
| Year | 2022 Resubmission (kt CO <sub>2</sub> -eq. AR4) | 2023 Submission (kt CO <sub>2</sub> eq. AR5) | Difference without GWP impact <sup>1</sup> (kt CO <sub>2</sub> eq. AR5) | 2022 Resubmission (kt CO <sub>2</sub> -eq. AR4) | 2023 Submission (kt CO <sub>2</sub> eq. AR5) | Difference without GWP impact <sup>1</sup> (kt CO <sub>2</sub> eq. AR5) |
| 1990 | 24 784                                          | 636                                          | 24 784                                                                  | 636                                             | 24 784                                       | 636                                                                     |
| 1991 | 21 445                                          | 649                                          | 21 445                                                                  | 649                                             | 21 445                                       | 649                                                                     |
| 1992 | 22 964                                          | 659                                          | 22 964                                                                  | 659                                             | 22 964                                       | 659                                                                     |
| 1993 | 22 983                                          | 662                                          | 22 983                                                                  | 662                                             | 22 983                                       | 662                                                                     |
| 1994 | 26 972                                          | 675                                          | 26 972                                                                  | 675                                             | 26 972                                       | 675                                                                     |
| 1995 | 23 331                                          | 676                                          | 23 331                                                                  | 676                                             | 23 331                                       | 676                                                                     |
| 1996 | 27 149                                          | 500                                          | 27 149                                                                  | 500                                             | 27 149                                       | 500                                                                     |
| 1997 | 28 326                                          | 211                                          | 28 326                                                                  | 211                                             | 28 326                                       | 211                                                                     |
| 1998 | 26 006                                          | -5                                           | 26 006                                                                  | -5                                              | 26 006                                       | -5                                                                      |
| 1999 | 25 119                                          | -93                                          | 25 119                                                                  | -93                                             | 25 119                                       | -93                                                                     |
| 2000 | 23 012                                          | -73                                          | 23 012                                                                  | -73                                             | 23 012                                       | -73                                                                     |
| 2001 | 22 468                                          | -28                                          | 22 468                                                                  | -28                                             | 22 468                                       | -28                                                                     |
| 2002 | 20 483                                          | 20                                           | 20 483                                                                  | 20                                              | 20 483                                       | 20                                                                      |
| 2003 | 20 233                                          | -2                                           | 20 233                                                                  | -2                                              | 20 233                                       | -2                                                                      |
| 2004 | 20 873                                          | -16                                          | 20 873                                                                  | -16                                             | 20 873                                       | -16                                                                     |
| 2005 | 22 517                                          | -68                                          | 22 517                                                                  | -68                                             | 22 517                                       | -68                                                                     |
| 2006 | 21 097                                          | -114                                         | 21 097                                                                  | -114                                            | 21 097                                       | -114                                                                    |
| 2007 | 22 723                                          | -145                                         | 22 723                                                                  | -145                                            | 22 723                                       | -145                                                                    |
| 2008 | 20 463                                          | -196                                         | 20 463                                                                  | -196                                            | 20 463                                       | -196                                                                    |
| 2009 | 15 444                                          | -227                                         | 15 444                                                                  | -227                                            | 15 444                                       | -227                                                                    |
| 2010 | 21 392                                          | -144                                         | 21 392                                                                  | -144                                            | 21 392                                       | -167                                                                    |
| 2011 | 19 185                                          | -153                                         | 19 185                                                                  | -153                                            | 19 185                                       | -152                                                                    |
| 2012 | 22 421                                          | -72                                          | 22 421                                                                  | -72                                             | 22 421                                       | -101                                                                    |



|             |        |       |        |       |        |       |
|-------------|--------|-------|--------|-------|--------|-------|
| <b>2013</b> | 22 173 | -96   | 22 173 | -96   | 22 173 | -124  |
| <b>2014</b> | 26 339 | -170  | 26 339 | -170  | 26 339 | -200  |
| <b>2015</b> | 31 702 | -346  | 31 702 | -346  | 31 702 | -379  |
| <b>2016</b> | 30 908 | -571  | 30 908 | -571  | 30 908 | -605  |
| <b>2017</b> | 31 226 | 1 294 | 31 226 | 1 294 | 31 226 | 1 291 |
| <b>2018</b> | 30 544 | 1 201 | 30 544 | 1 201 | 30 544 | 930   |
| <b>2019</b> | 26 969 | 1 066 | 26 969 | 1 066 | 26 969 | 784   |
| <b>2020</b> | 21 551 | 1 132 | 21 551 | 1 132 | 21 551 | 875   |

<sup>1</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

**Table 10-30 Implications of recalculations for CH<sub>4</sub> emissions (in CO<sub>2</sub>-eq. including LULUCF)**

| <b>Year</b> | <b>2022 Resubmission (kt CO<sub>2</sub>-eq. AR4)</b> | <b>2023 Submission (kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP change<sup>1</sup> (kt CO<sub>2</sub> eq.)</b> | <b>Difference without GWP impact<sup>2</sup> (kt CO<sub>2</sub> eq. AR5)</b> |
|-------------|------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------|
| <b>1990</b> | 6 405                                                | 7 171                                              | 769                                                             | -2                                                                           |
| <b>1991</b> | 6 268                                                | 7 018                                              | 752                                                             | -2                                                                           |
| <b>1992</b> | 6 354                                                | 7 114                                              | 762                                                             | -2                                                                           |
| <b>1993</b> | 6 497                                                | 7 276                                              | 780                                                             | -1                                                                           |
| <b>1994</b> | 6 583                                                | 7 373                                              | 790                                                             | 0                                                                            |
| <b>1995</b> | 6 588                                                | 7 379                                              | 791                                                             | -0                                                                           |
| <b>1996</b> | 6 595                                                | 7 387                                              | 791                                                             | -0                                                                           |
| <b>1997</b> | 6 620                                                | 7 414                                              | 794                                                             | -0                                                                           |
| <b>1998</b> | 6 391                                                | 7 159                                              | 767                                                             | 1                                                                            |
| <b>1999</b> | 6 341                                                | 7 105                                              | 761                                                             | 3                                                                            |
| <b>2000</b> | 6 351                                                | 7 116                                              | 762                                                             | 3                                                                            |
| <b>2001</b> | 6 341                                                | 7 105                                              | 761                                                             | 3                                                                            |
| <b>2002</b> | 6 209                                                | 6 956                                              | 745                                                             | 2                                                                            |
| <b>2003</b> | 6 181                                                | 6 925                                              | 742                                                             | 2                                                                            |
| <b>2004</b> | 6 069                                                | 6 802                                              | 728                                                             | 5                                                                            |

|      |       |       |     |    |
|------|-------|-------|-----|----|
| 2005 | 5 919 | 6 632 | 710 | 3  |
| 2006 | 5 776 | 6 472 | 693 | 3  |
| 2007 | 5 859 | 6 565 | 703 | 3  |
| 2008 | 5 712 | 6 400 | 685 | 2  |
| 2009 | 5 751 | 6 441 | 690 | 0  |
| 2010 | 5 757 | 6 450 | 691 | 3  |
| 2011 | 5 635 | 6 312 | 676 | 1  |
| 2012 | 5 544 | 6 208 | 665 | -2 |
| 2013 | 5 463 | 6 118 | 656 | -1 |
| 2014 | 5 407 | 6 057 | 649 | 1  |
| 2015 | 5 403 | 6 055 | 648 | 3  |
| 2016 | 5 317 | 5 959 | 638 | 4  |
| 2017 | 5 177 | 5 801 | 621 | 3  |
| 2018 | 5 099 | 5 714 | 612 | 3  |
| 2019 | 4 922 | 5 510 | 591 | -3 |
| 2020 | 4 899 | 5 498 | 588 | 12 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

| Table 10-31 Implications of recalculations for N <sub>2</sub> O emissions (in CO <sub>2</sub> -eq. including LULUCF) |                                                 |                                              |                                                            |                                                                         |
|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------------|
| Year                                                                                                                 | 2022 Resubmission (kt CO <sub>2</sub> -eq. AR4) | 2023 Submission (kt CO <sub>2</sub> eq. AR5) | Impact of GWP change <sup>1</sup> (kt CO <sub>2</sub> eq.) | Difference without GWP impact <sup>2</sup> (kt CO <sub>2</sub> eq. AR5) |
| 1990                                                                                                                 | 4 343                                           | 3 858                                        | -481                                                       | -4                                                                      |
| 1991                                                                                                                 | 4 189                                           | 3 724                                        | -464                                                       | -1                                                                      |
| 1992                                                                                                                 | 3 655                                           | 3 250                                        | -405                                                       | -1                                                                      |
| 1993                                                                                                                 | 3 854                                           | 3 425                                        | -427                                                       | -2                                                                      |
| 1994                                                                                                                 | 3 925                                           | 3 485                                        | -435                                                       | -5                                                                      |

|             |       |       |      |     |
|-------------|-------|-------|------|-----|
| <b>1995</b> | 3 952 | 3 509 | -438 | -6  |
| <b>1996</b> | 3 970 | 3 523 | -440 | -8  |
| <b>1997</b> | 3 963 | 3 517 | -439 | -7  |
| <b>1998</b> | 4 055 | 3 602 | -449 | -3  |
| <b>1999</b> | 4 270 | 3 792 | -473 | -5  |
| <b>2000</b> | 4 067 | 3 617 | -450 | 0   |
| <b>2001</b> | 3 997 | 3 546 | -443 | -8  |
| <b>2002</b> | 4 244 | 3 765 | -470 | -8  |
| <b>2003</b> | 4 098 | 3 634 | -454 | -10 |
| <b>2004</b> | 4 240 | 3 759 | -470 | -11 |
| <b>2005</b> | 4 312 | 3 823 | -477 | -12 |
| <b>2006</b> | 3 982 | 3 531 | -441 | -10 |
| <b>2007</b> | 3 802 | 3 369 | -421 | -12 |
| <b>2008</b> | 3 364 | 2 979 | -373 | -13 |
| <b>2009</b> | 2 817 | 2 492 | -312 | -13 |
| <b>2010</b> | 2 729 | 2 416 | -302 | -11 |
| <b>2011</b> | 2 721 | 2 407 | -301 | -13 |
| <b>2012</b> | 2 732 | 2 416 | -303 | -14 |
| <b>2013</b> | 2 708 | 2 397 | -300 | -11 |
| <b>2014</b> | 2 719 | 2 405 | -301 | -13 |
| <b>2015</b> | 2 759 | 2 440 | -305 | -13 |
| <b>2016</b> | 2 701 | 2 398 | -299 | -4  |
| <b>2017</b> | 2 653 | 2 357 | -294 | -3  |
| <b>2018</b> | 2 629 | 2 331 | -291 | -6  |
| <b>2019</b> | 2 648 | 2 349 | -293 | -6  |
| <b>2020</b> | 2 578 | 2 305 | -286 | 12  |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

| <b>Table 10-32 Implications of recalculations for HFK emissions (in CO<sub>2</sub>-eq. including LULUCF)</b> |                                                      |                                                    |                                                                 |                                                                              |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------|
| <b>Year</b>                                                                                                  | <b>2022 Resubmission (kt CO<sub>2</sub> eq. AR4)</b> | <b>2023 Submission (kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP change<sup>1</sup> (kt CO<sub>2</sub> eq.)</b> | <b>Difference without GWP impact<sup>2</sup> (kt CO<sub>2</sub> eq. AR5)</b> |
| <b>1990</b>                                                                                                  | 0                                                    | 0                                                  | 0                                                               | 0                                                                            |
| <b>1991</b>                                                                                                  | 1                                                    | 1                                                  | -0                                                              | -0                                                                           |
| <b>1992</b>                                                                                                  | 3                                                    | 3                                                  | -0                                                              | 0                                                                            |
| <b>1993</b>                                                                                                  | 36                                                   | 33                                                 | -3                                                              | -0                                                                           |
| <b>1994</b>                                                                                                  | 54                                                   | 50                                                 | -4                                                              | 0                                                                            |
| <b>1995</b>                                                                                                  | 98                                                   | 92                                                 | -6                                                              | 0                                                                            |
| <b>1996</b>                                                                                                  | 130                                                  | 123                                                | -7                                                              | 0                                                                            |
| <b>1997</b>                                                                                                  | 195                                                  | 186                                                | -9                                                              | -0                                                                           |
| <b>1998</b>                                                                                                  | 258                                                  | 246                                                | -12                                                             | -0                                                                           |
| <b>1999</b>                                                                                                  | 323                                                  | 310                                                | -13                                                             | 0                                                                            |
| <b>2000</b>                                                                                                  | 369                                                  | 357                                                | -13                                                             | 0                                                                            |
| <b>2001</b>                                                                                                  | 467                                                  | 452                                                | -14                                                             | 0                                                                            |
| <b>2002</b>                                                                                                  | 504                                                  | 490                                                | -14                                                             | -0                                                                           |
| <b>2003</b>                                                                                                  | 516                                                  | 500                                                | -16                                                             | -0                                                                           |
| <b>2004</b>                                                                                                  | 544                                                  | 527                                                | -17                                                             | -0                                                                           |
| <b>2005</b>                                                                                                  | 549                                                  | 528                                                | -21                                                             | 0                                                                            |
| <b>2006</b>                                                                                                  | 620                                                  | 596                                                | -25                                                             | 0                                                                            |
| <b>2007</b>                                                                                                  | 684                                                  | 657                                                | -27                                                             | -0                                                                           |
| <b>2008</b>                                                                                                  | 739                                                  | 709                                                | -30                                                             | 0                                                                            |
| <b>2009</b>                                                                                                  | 819                                                  | 784                                                | -35                                                             | -0                                                                           |
| <b>2010</b>                                                                                                  | 894                                                  | 855                                                | -39                                                             | -0                                                                           |
| <b>2011</b>                                                                                                  | 966                                                  | 923                                                | -42                                                             | -0                                                                           |
| <b>2012</b>                                                                                                  | 1 028                                                | 980                                                | -48                                                             | 0                                                                            |

|             |       |       |     |    |
|-------------|-------|-------|-----|----|
| <b>2013</b> | 1 118 | 1 068 | -50 | 0  |
| <b>2014</b> | 1 081 | 1 028 | -54 | 1  |
| <b>2015</b> | 963   | 910   | -54 | 1  |
| <b>2016</b> | 1 005 | 951   | -55 | 1  |
| <b>2017</b> | 1 029 | 973   | -57 | 0  |
| <b>2018</b> | 997   | 940   | -57 | 0  |
| <b>2019</b> | 934   | 874   | -59 | -0 |
| <b>2020</b> | 810   | 750   | -59 | -1 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

**Table 10-33 Implications of recalculations for PFK emissions (in CO<sub>2</sub>-eq. including LULUCF)**

| <b>Year</b> | <b>2022 Resubmission (kt CO<sub>2</sub>-eq. AR4)</b> | <b>2023 Submission (kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP change<sup>1</sup> (kt CO<sub>2</sub> eq.)</b> | <b>Difference without GWP impact<sup>2</sup> (kt CO<sub>2</sub> eq. AR5)</b> |
|-------------|------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------|
| <b>1990</b> | 3 895                                                | 3 500                                              | -395                                                            | -                                                                            |
| <b>1991</b> | 3 457                                                | 3 106                                              | -351                                                            | -                                                                            |
| <b>1992</b> | 2 637                                                | 2 369                                              | -268                                                            | -                                                                            |
| <b>1993</b> | 2 648                                                | 2 379                                              | -269                                                            | -                                                                            |
| <b>1994</b> | 2 343                                                | 2 104                                              | -238                                                            | -                                                                            |
| <b>1995</b> | 2 314                                                | 2 079                                              | -235                                                            | -                                                                            |
| <b>1996</b> | 2 108                                                | 1 893                                              | -214                                                            | -                                                                            |
| <b>1997</b> | 1 883                                                | 1 691                                              | -191                                                            | -                                                                            |
| <b>1998</b> | 1 712                                                | 1 538                                              | -174                                                            | -                                                                            |
| <b>1999</b> | 1 600                                                | 1 437                                              | -163                                                            | -                                                                            |
| <b>2000</b> | 1 518                                                | 1 364                                              | -154                                                            | -                                                                            |
| <b>2001</b> | 1 531                                                | 1 376                                              | -156                                                            | -                                                                            |
| <b>2002</b> | 1 659                                                | 1 490                                              | -168                                                            | -                                                                            |
| <b>2003</b> | 1 051                                                | 945                                                | -107                                                            | -                                                                            |

|             |       |     |      |   |
|-------------|-------|-----|------|---|
| <b>2004</b> | 1 017 | 914 | -103 | - |
| <b>2005</b> | 955   | 858 | -97  | - |
| <b>2006</b> | 859   | 772 | -87  | - |
| <b>2007</b> | 951   | 855 | -96  | - |
| <b>2008</b> | 896   | 805 | -91  | - |
| <b>2009</b> | 438   | 394 | -44  | - |
| <b>2010</b> | 238   | 214 | -24  | - |
| <b>2011</b> | 263   | 236 | -26  | - |
| <b>2012</b> | 200   | 180 | -20  | - |
| <b>2013</b> | 181   | 163 | -18  | - |
| <b>2014</b> | 179   | 161 | -18  | - |
| <b>2015</b> | 146   | 132 | -15  | - |
| <b>2016</b> | 186   | 167 | -19  | - |
| <b>2017</b> | 131   | 118 | -13  | - |
| <b>2018</b> | 148   | 133 | -15  | - |
| <b>2019</b> | 175   | 157 | -18  | - |
| <b>2020</b> | 161   | 145 | -16  | - |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

| <b>Table 10-34 Implications of recalculations for SF6 emissions (in CO<sub>2</sub>-eq. including LULUCF)</b> |                                                      |                                                    |                                                                 |                                                                              |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------|
| <b>Year</b>                                                                                                  | <b>2022 Resubmission (kt CO<sub>2</sub>-eq. AR4)</b> | <b>2023 Submission (kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP change<sup>1</sup> (kt CO<sub>2</sub> eq.)</b> | <b>Difference without GWP impact<sup>2</sup> (kt CO<sub>2</sub> eq. AR5)</b> |
| <b>1990</b>                                                                                                  | 2 099                                                | 2 163                                              | 64                                                              | -                                                                            |
| <b>1991</b>                                                                                                  | 1 983                                                | 2 044                                              | 61                                                              | -                                                                            |
| <b>1992</b>                                                                                                  | 673                                                  | 693                                                | 21                                                              | -                                                                            |
| <b>1993</b>                                                                                                  | 704                                                  | 725                                                | 22                                                              | -                                                                            |
| <b>1994</b>                                                                                                  | 838                                                  | 863                                                | 26                                                              | -                                                                            |

|             |     |     |    |   |
|-------------|-----|-----|----|---|
| <b>1995</b> | 580 | 598 | 18 | - |
| <b>1996</b> | 548 | 564 | 17 | - |
| <b>1997</b> | 553 | 570 | 17 | - |
| <b>1998</b> | 693 | 714 | 21 | - |
| <b>1999</b> | 834 | 859 | 26 | - |
| <b>2000</b> | 891 | 919 | 27 | - |
| <b>2001</b> | 755 | 778 | 23 | - |
| <b>2002</b> | 227 | 234 | 7  | - |
| <b>2003</b> | 216 | 222 | 7  | - |
| <b>2004</b> | 261 | 269 | 8  | - |
| <b>2005</b> | 297 | 306 | 9  | - |
| <b>2006</b> | 203 | 209 | 6  | - |
| <b>2007</b> | 71  | 73  | 2  | - |
| <b>2008</b> | 61  | 63  | 2  | - |
| <b>2009</b> | 56  | 58  | 2  | - |
| <b>2010</b> | 68  | 71  | 2  | - |
| <b>2011</b> | 54  | 55  | 2  | - |
| <b>2012</b> | 53  | 54  | 2  | - |
| <b>2013</b> | 55  | 57  | 2  | - |
| <b>2014</b> | 49  | 50  | 1  | - |
| <b>2015</b> | 68  | 70  | 2  | - |
| <b>2016</b> | 61  | 63  | 2  | - |
| <b>2017</b> | 56  | 58  | 2  | - |
| <b>2018</b> | 54  | 56  | 2  | - |
| <b>2019</b> | 68  | 70  | 2  | - |
| <b>2020</b> | 74  | 76  | 2  | - |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

| <b>Table 10-35 Implications of reallocation of indirect CO<sub>2</sub> for total emissions (Excluding LULUCF)</b> |                                                                                            |                                                                                         |                                |
|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--------------------------------|
| <b>Year</b>                                                                                                       | <b>2023 Submission<br/>(kt CO<sub>2</sub> eq. AR5)<br/>without indirect CO<sub>2</sub></b> | <b>2023 Submission<br/>(kt CO<sub>2</sub> eq. AR5)<br/>with indirect CO<sub>2</sub></b> | <b>Indirect CO<sub>2</sub></b> |
| 1990                                                                                                              | 50 712                                                                                     | 51 305                                                                                  | 593                            |
| 1991                                                                                                              | 48 339                                                                                     | 48 955                                                                                  | 616                            |
| 1992                                                                                                              | 46 707                                                                                     | 47 419                                                                                  | 713                            |
| 1993                                                                                                              | 48 599                                                                                     | 49 378                                                                                  | 780                            |
| 1994                                                                                                              | 50 502                                                                                     | 51 330                                                                                  | 828                            |
| 1995                                                                                                              | 50 834                                                                                     | 51 717                                                                                  | 883                            |
| 1996                                                                                                              | 53 717                                                                                     | 54 617                                                                                  | 899                            |
| 1997                                                                                                              | 53 693                                                                                     | 54 606                                                                                  | 913                            |
| 1998                                                                                                              | 53 765                                                                                     | 54 672                                                                                  | 906                            |
| 1999                                                                                                              | 54 741                                                                                     | 55 683                                                                                  | 941                            |
| 2000                                                                                                              | 54 074                                                                                     | 55 070                                                                                  | 996                            |
| 2001                                                                                                              | 55 299                                                                                     | 56 339                                                                                  | 1 040                          |
| 2002                                                                                                              | 54 173                                                                                     | 55 078                                                                                  | 905                            |
| 2003                                                                                                              | 54 948                                                                                     | 55 717                                                                                  | 770                            |
| 2004                                                                                                              | 55 428                                                                                     | 56 101                                                                                  | 673                            |
| 2005                                                                                                              | 54 472                                                                                     | 55 003                                                                                  | 531                            |
| 2006                                                                                                              | 54 569                                                                                     | 55 015                                                                                  | 446                            |
| 2007                                                                                                              | 56 273                                                                                     | 56 712                                                                                  | 440                            |
| 2008                                                                                                              | 54 882                                                                                     | 55 232                                                                                  | 350                            |
| 2009                                                                                                              | 52 541                                                                                     | 52 855                                                                                  | 314                            |
| 2010                                                                                                              | 54 925                                                                                     | 55 233                                                                                  | 308                            |
| 2011                                                                                                              | 53 999                                                                                     | 54 289                                                                                  | 290                            |
| 2012                                                                                                              | 53 381                                                                                     | 53 671                                                                                  | 290                            |
| 2013                                                                                                              | 53 615                                                                                     | 53 916                                                                                  | 301                            |
| 2014                                                                                                              | 53 907                                                                                     | 54 246                                                                                  | 339                            |
| 2015                                                                                                              | 54 363                                                                                     | 54 691                                                                                  | 328                            |



|             |        |        |     |
|-------------|--------|--------|-----|
| <b>2016</b> | 53 447 | 53 765 | 318 |
| <b>2017</b> | 52 679 | 52 981 | 302 |
| <b>2018</b> | 52 703 | 53 001 | 298 |
| <b>2019</b> | 50 958 | 51 219 | 260 |
| <b>2020</b> | 49 215 | 49 498 | 283 |

Table 10-36, Table 10-37, Table 10-38, Table 10-39 and Table 10-40 show the effects of recalculations for CO<sub>2</sub> equivalents per sector, with the effect of new GWP values and reallocation of indirect CO<sub>2</sub> isolated.

**Table 10-36 Implications of recalculations for emissions in the energy sector (in CO<sub>2</sub>-eq.)**

| <b>Year</b> | <b>2022 Resubmission<br/>(kt CO<sub>2</sub> eq.<br/>AR4)</b> | <b>2023 Submission<br/>(kt CO<sub>2</sub> eq.<br/>AR5)</b> | <b>Impact of<br/>GWP<br/>change<sup>1</sup><br/>(kt CO<sub>2</sub> eq.)</b> | <b>Reallocation<br/>of indirect CO<sub>2</sub><br/>(kt)</b> | <b>Difference<br/>without GWP<br/>impact and<br/>reallocation<br/>of indirect<br/>CO<sub>2</sub><sup>2</sup><br/>(kt CO<sub>2</sub> eq.<br/>AR5)</b> |
|-------------|--------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1990</b> | 28 840                                                       | 28 397                                                     | 112                                                                         | -472                                                        | -84                                                                                                                                                  |
| <b>1991</b> | 27 785                                                       | 27 321                                                     | 113                                                                         | -510                                                        | -68                                                                                                                                                  |
| <b>1992</b> | 28 910                                                       | 28 373                                                     | 123                                                                         | -603                                                        | -58                                                                                                                                                  |
| <b>1993</b> | 30 061                                                       | 29 479                                                     | 141                                                                         | -669                                                        | -54                                                                                                                                                  |
| <b>1994</b> | 31 670                                                       | 31 065                                                     | 147                                                                         | -710                                                        | -42                                                                                                                                                  |
| <b>1995</b> | 32 141                                                       | 31 477                                                     | 145                                                                         | -768                                                        | -40                                                                                                                                                  |
| <b>1996</b> | 35 199                                                       | 34 536                                                     | 152                                                                         | -778                                                        | -37                                                                                                                                                  |
| <b>1997</b> | 35 027                                                       | 34 301                                                     | 164                                                                         | -795                                                        | -94                                                                                                                                                  |
| <b>1998</b> | 34 934                                                       | 34 260                                                     | 156                                                                         | -788                                                        | -42                                                                                                                                                  |
| <b>1999</b> | 35 922                                                       | 35 213                                                     | 154                                                                         | -825                                                        | -37                                                                                                                                                  |
| <b>2000</b> | 35 050                                                       | 34 304                                                     | 165                                                                         | -885                                                        | -25                                                                                                                                                  |
| <b>2001</b> | 36 809                                                       | 36 036                                                     | 172                                                                         | -927                                                        | -18                                                                                                                                                  |
| <b>2002</b> | 36 540                                                       | 35 895                                                     | 169                                                                         | -790                                                        | -24                                                                                                                                                  |
| <b>2003</b> | 37 755                                                       | 37 165                                                     | 162                                                                         | -654                                                        | -97                                                                                                                                                  |
| <b>2004</b> | 37 435                                                       | 36 945                                                     | 154                                                                         | -555                                                        | -89                                                                                                                                                  |
| <b>2005</b> | 36 910                                                       | 36 541                                                     | 148                                                                         | -424                                                        | -93                                                                                                                                                  |
| <b>2006</b> | 37 710                                                       | 37 402                                                     | 135                                                                         | -348                                                        | -96                                                                                                                                                  |
| <b>2007</b> | 39 424                                                       | 39 142                                                     | 149                                                                         | -341                                                        | -90                                                                                                                                                  |
| <b>2008</b> | 38 136                                                       | 37 888                                                     | 138                                                                         | -254                                                        | -132                                                                                                                                                 |
| <b>2009</b> | 38 168                                                       | 37 917                                                     | 138                                                                         | -234                                                        | -155                                                                                                                                                 |
| <b>2010</b> | 39 687                                                       | 39 515                                                     | 140                                                                         | -212                                                        | -101                                                                                                                                                 |
| <b>2011</b> | 38 569                                                       | 38 411                                                     | 131                                                                         | -192                                                        | -98                                                                                                                                                  |

|             |        |        |     |      |      |
|-------------|--------|--------|-----|------|------|
| <b>2012</b> | 38 138 | 37 973 | 129 | -189 | -105 |
| <b>2013</b> | 38 253 | 38 043 | 120 | -197 | -133 |
| <b>2014</b> | 38 530 | 38 289 | 116 | -222 | -135 |
| <b>2015</b> | 38 991 | 38 750 | 117 | -217 | -141 |
| <b>2016</b> | 38 130 | 37 898 | 106 | -201 | -137 |
| <b>2017</b> | 37 503 | 37 233 | 99  | -179 | -190 |
| <b>2018</b> | 37 520 | 37 262 | 94  | -181 | -171 |
| <b>2019</b> | 35 927 | 35 691 | 91  | -169 | -159 |
| <b>2020</b> | 34 188 | 34 023 | 95  | -157 | -103 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5.

**Table 10-37 Implications of recalculations for emissions in the IPPU sector (in CO<sub>2</sub>-eq.)**

| <b>Year</b> | <b>2022 Resubmission (kt CO<sub>2</sub>-eq. AR4)</b> | <b>2023 Submission (kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP change<sup>1</sup> (kt CO<sub>2</sub> eq.)</b> | <b>Reallocation of indirect CO<sub>2</sub> (kt)</b> | <b>Difference without GWP impact and reallocation of indirect CO<sub>2</sub><sup>2</sup> (kt CO<sub>2</sub> eq. AR5)</b> |
|-------------|------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| <b>1990</b> | 15 377                                               | 14 697                                             | -559                                                            | -121                                                | 0                                                                                                                        |
| <b>1991</b> | 14 189                                               | 13 581                                             | -502                                                            | -106                                                | 0                                                                                                                        |
| <b>1992</b> | 11 458                                               | 10 948                                             | -401                                                            | -110                                                | 0                                                                                                                        |
| <b>1993</b> | 12 268                                               | 11 731                                             | -427                                                            | -110                                                | 0                                                                                                                        |
| <b>1994</b> | 12 569                                               | 12 052                                             | -400                                                            | -118                                                | 0                                                                                                                        |
| <b>1995</b> | 12 436                                               | 11 914                                             | -407                                                            | -115                                                | 0                                                                                                                        |
| <b>1996</b> | 12 310                                               | 11 803                                             | -386                                                            | -121                                                | 0                                                                                                                        |
| <b>1997</b> | 12 598                                               | 12 117                                             | -363                                                            | -118                                                | 0                                                                                                                        |
| <b>1998</b> | 12 894                                               | 12 423                                             | -353                                                            | -119                                                | 0                                                                                                                        |
| <b>1999</b> | 12 960                                               | 12 481                                             | -363                                                            | -116                                                | 0                                                                                                                        |
| <b>2000</b> | 13 220                                               | 12 777                                             | -333                                                            | -111                                                | 0                                                                                                                        |

|      |        |        |      |      |    |
|------|--------|--------|------|------|----|
| 2001 | 12 827 | 12 380 | -334 | -113 | 0  |
| 2002 | 12 027 | 11 522 | -390 | -115 | 0  |
| 2003 | 11 379 | 10 953 | -310 | -115 | -0 |
| 2004 | 12 127 | 11 687 | -322 | -118 | 0  |
| 2005 | 11 669 | 11 229 | -329 | -107 | -4 |
| 2006 | 10 931 | 10 532 | -292 | -99  | -8 |
| 2007 | 10 905 | 10 521 | -285 | -99  | -1 |
| 2008 | 10 806 | 10 475 | -235 | -95  | -0 |
| 2009 | 8 371  | 8 152  | -139 | -80  | -0 |
| 2010 | 9 102  | 8 890  | -117 | -96  | -0 |
| 2011 | 9 240  | 9 024  | -118 | -98  | -0 |
| 2012 | 9 170  | 8 952  | -116 | -101 | -1 |
| 2013 | 9 302  | 9 087  | -111 | -104 | 0  |
| 2014 | 9 311  | 9 084  | -111 | -117 | 1  |
| 2015 | 9 317  | 9 098  | -109 | -111 | 1  |
| 2016 | 9 263  | 9 039  | -107 | -118 | 1  |
| 2017 | 9 246  | 9 023  | -99  | -123 | 0  |
| 2018 | 9 296  | 9 081  | -99  | -116 | 0  |
| 2019 | 9 259  | 9 064  | -103 | -91  | -0 |
| 2020 | 9 224  | 9 001  | -96  | -126 | -1 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5

**Table 10-38 Implications of recalculations for emissions in the agriculture sector (in CO<sub>2</sub>-eq)**

| Year | 2022 Resubmission<br>(kt CO <sub>2</sub> -eq. AR4) | 2023 Submission<br>(kt CO <sub>2</sub> eq. AR5) | Impact of GWP<br>change <sup>1</sup><br>(kt CO <sub>2</sub> eq.) | Difference<br>without GWP<br>impact and<br>reallocation of<br>indirect CO <sub>2</sub> <sup>2</sup><br>(kt CO <sub>2</sub> eq. AR5) |
|------|----------------------------------------------------|-------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
|------|----------------------------------------------------|-------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|

|             |       |       |     |    |
|-------------|-------|-------|-----|----|
| <b>1990</b> | 4 812 | 4 947 | 134 | 0  |
| <b>1991</b> | 4 746 | 4 878 | 131 | 0  |
| <b>1992</b> | 4 713 | 4 848 | 133 | 1  |
| <b>1993</b> | 4 707 | 4 841 | 134 | 1  |
| <b>1994</b> | 4 709 | 4 851 | 140 | 1  |
| <b>1995</b> | 4 749 | 4 889 | 138 | 1  |
| <b>1996</b> | 4 783 | 4 924 | 139 | 1  |
| <b>1997</b> | 4 727 | 4 863 | 134 | 2  |
| <b>1998</b> | 4 720 | 4 855 | 133 | 2  |
| <b>1999</b> | 4 738 | 4 882 | 140 | 4  |
| <b>2000</b> | 4 586 | 4 715 | 125 | 3  |
| <b>2001</b> | 4 536 | 4 667 | 128 | 3  |
| <b>2002</b> | 4 519 | 4 649 | 126 | 3  |
| <b>2003</b> | 4 597 | 4 727 | 127 | 3  |
| <b>2004</b> | 4 562 | 4 688 | 123 | 3  |
| <b>2005</b> | 4 569 | 4 697 | 124 | 3  |
| <b>2006</b> | 4 482 | 4 606 | 121 | 3  |
| <b>2007</b> | 4 475 | 4 594 | 117 | 3  |
| <b>2008</b> | 4 459 | 4 579 | 119 | 2  |
| <b>2009</b> | 4 442 | 4 571 | 128 | 1  |
| <b>2010</b> | 4 361 | 4 494 | 133 | 1  |
| <b>2011</b> | 4 333 | 4 453 | 120 | -0 |
| <b>2012</b> | 4 352 | 4 471 | 121 | -1 |
| <b>2013</b> | 4 403 | 4 523 | 121 | -1 |
| <b>2014</b> | 4 473 | 4 594 | 119 | 2  |
| <b>2015</b> | 4 538 | 4 662 | 121 | 3  |
| <b>2016</b> | 4 587 | 4 719 | 127 | 4  |

|             |       |       |     |    |
|-------------|-------|-------|-----|----|
| <b>2017</b> | 4 564 | 4 695 | 128 | 3  |
| <b>2018</b> | 4 542 | 4 673 | 128 | 4  |
| <b>2019</b> | 4 518 | 4 631 | 115 | -2 |
| <b>2020</b> | 4 510 | 4 649 | 115 | 24 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5

**Table 10-39 Implications of recalculations for emissions in the LULUCF sector (in CO<sub>2</sub>-eq)**

| <b>Year</b> | <b>2022 Resubmission<br/>(kt CO<sub>2</sub>-eq. AR4)</b> | <b>2023 Submission<br/>(kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP<br/>change<sup>1</sup><br/>(kt CO<sub>2</sub> eq.)</b> | <b>Difference<br/>without GWP<br/>impact and<br/>reallocation of<br/>indirect CO<sub>2</sub> <sup>2</sup><br/>(kt CO<sub>2</sub> eq. AR5)</b> |
|-------------|----------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1990</b> | -10 542                                                  | -9 829                                                 | -6                                                                      | 719                                                                                                                                           |
| <b>1991</b> | -12 330                                                  | -11 616                                                | -6                                                                      | 721                                                                                                                                           |
| <b>1992</b> | -11 741                                                  | -11 026                                                | -6                                                                      | 721                                                                                                                                           |
| <b>1993</b> | -13 271                                                  | -12 557                                                | -6                                                                      | 720                                                                                                                                           |
| <b>1994</b> | -11 198                                                  | -10 483                                                | -6                                                                      | 721                                                                                                                                           |
| <b>1995</b> | -15 444                                                  | -14 730                                                | -6                                                                      | 720                                                                                                                                           |
| <b>1996</b> | -14 512                                                  | -13 977                                                | -6                                                                      | 541                                                                                                                                           |
| <b>1997</b> | -13 203                                                  | -12 901                                                | -6                                                                      | 308                                                                                                                                           |
| <b>1998</b> | -15 440                                                  | -15 406                                                | -7                                                                      | 41                                                                                                                                            |
| <b>1999</b> | -17 003                                                  | -17 059                                                | -7                                                                      | -50                                                                                                                                           |
| <b>2000</b> | -18 641                                                  | -18 687                                                | -6                                                                      | -39                                                                                                                                           |
| <b>2001</b> | -20 607                                                  | -20 615                                                | -6                                                                      | -2                                                                                                                                            |
| <b>2002</b> | -21 704                                                  | -21 659                                                | -7                                                                      | 52                                                                                                                                            |
| <b>2003</b> | -23 317                                                  | -23 259                                                | -7                                                                      | 65                                                                                                                                            |
| <b>2004</b> | -22 994                                                  | -22 957                                                | -6                                                                      | 43                                                                                                                                            |
| <b>2005</b> | -20 329                                                  | -20 340                                                | -6                                                                      | -4                                                                                                                                            |
| <b>2006</b> | -22 283                                                  | -22 339                                                | -6                                                                      | -50                                                                                                                                           |

|             |         |         |    |       |
|-------------|---------|---------|----|-------|
| <b>2007</b> | -22 370 | -22 470 | -6 | -94   |
| <b>2008</b> | -23 699 | -23 812 | -6 | -106  |
| <b>2009</b> | -27 119 | -27 241 | -6 | -116  |
| <b>2010</b> | -23 716 | -23 834 | -7 | -112  |
| <b>2011</b> | -25 015 | -25 170 | -7 | -148  |
| <b>2012</b> | -21 362 | -21 412 | -7 | -43   |
| <b>2013</b> | -21 877 | -21 941 | -7 | -57   |
| <b>2014</b> | -18 098 | -18 206 | -6 | -102  |
| <b>2015</b> | -13 101 | -13 382 | -6 | -275  |
| <b>2016</b> | -12 836 | -13 320 | -7 | -476  |
| <b>2017</b> | -13 863 | -12 449 | -7 | 1 420 |
| <b>2018</b> | -14 601 | -13 282 | -6 | 1 326 |
| <b>2019</b> | -16 436 | -15 289 | -6 | 1 153 |
| <b>2020</b> | -20 332 | -19 173 | -6 | 1 166 |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5

**Table 10-40 Implications of recalculations for emissions in the waste sector (in CO<sub>2</sub>-eq)**

| <b>Year</b> | <b>2022 Resubmission<br/>(kt CO<sub>2</sub> eq. AR4)</b> | <b>2023 Submission<br/>(kt CO<sub>2</sub> eq. AR5)</b> | <b>Impact of GWP<br/>change<sup>1</sup><br/>(kt CO<sub>2</sub> eq.)</b> | <b>Difference<br/>without GWP<br/>impact and<br/>reallocation of<br/>indirect CO<sub>2</sub><sup>2</sup><br/>(kt CO<sub>2</sub> eq. AR5)</b> |
|-------------|----------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1990</b> | 2 403                                                    | 2 671                                                  | 275                                                                     | -7                                                                                                                                           |
| <b>1991</b> | 2 305                                                    | 2 560                                                  | 263                                                                     | -8                                                                                                                                           |
| <b>1992</b> | 2 287                                                    | 2 539                                                  | 261                                                                     | -9                                                                                                                                           |
| <b>1993</b> | 2 296                                                    | 2 548                                                  | 261                                                                     | -9                                                                                                                                           |
| <b>1994</b> | 2 288                                                    | 2 535                                                  | 258                                                                     | -11                                                                                                                                          |
| <b>1995</b> | 2 306                                                    | 2 555                                                  | 260                                                                     | -11                                                                                                                                          |

|             |       |       |     |     |
|-------------|-------|-------|-----|-----|
| <b>1996</b> | 2 219 | 2 455 | 249 | -13 |
| <b>1997</b> | 2 181 | 2 413 | 244 | -13 |
| <b>1998</b> | 2 013 | 2 227 | 223 | -9  |
| <b>1999</b> | 1 963 | 2 165 | 214 | -12 |
| <b>2000</b> | 2 066 | 2 278 | 221 | -9  |
| <b>2001</b> | 2 020 | 2 215 | 212 | -17 |
| <b>2002</b> | 1 924 | 2 107 | 201 | -18 |
| <b>2003</b> | 1 883 | 2 102 | 200 | 19  |
| <b>2004</b> | 1 890 | 2 108 | 198 | 20  |
| <b>2005</b> | 1 797 | 2 005 | 187 | 21  |
| <b>2006</b> | 1 810 | 2 029 | 190 | 29  |
| <b>2007</b> | 1 801 | 2 016 | 186 | 29  |
| <b>2008</b> | 1 730 | 1 939 | 178 | 31  |
| <b>2009</b> | 1 691 | 1 901 | 180 | 30  |
| <b>2010</b> | 1 788 | 2 026 | 178 | 59  |
| <b>2011</b> | 1 849 | 2 112 | 181 | 82  |
| <b>2012</b> | 1 753 | 1 985 | 169 | 63  |
| <b>2013</b> | 1 714 | 1 962 | 165 | 83  |
| <b>2014</b> | 1 726 | 1 940 | 160 | 54  |
| <b>2015</b> | 1 642 | 1 853 | 153 | 57  |
| <b>2016</b> | 1 605 | 1 791 | 147 | 38  |
| <b>2017</b> | 1 528 | 1 727 | 138 | 61  |
| <b>2018</b> | 1 514 | 1 687 | 134 | 40  |
| <b>2019</b> | 1 382 | 1 573 | 126 | 65  |
| <b>2020</b> | 1 351 | 1 541 | 122 | 69  |

<sup>1</sup>The difference between the 2022 resubmission using GWP from AR4 and AR5, respectively.

<sup>2</sup>The difference between the 2023 submission and the 2022 resubmission using GWP from AR5



### 10.3.2 Implications for emission trends

The national emissions without LULUCF decreased by 3,5 per cent between base year (1990) and 2020. The equivalent figure was 4.2 per cent in the previous submission.

When including LULUCF in the national totals, the change in trend between 1990 and 2020 from 29 per cent to 27 per cent

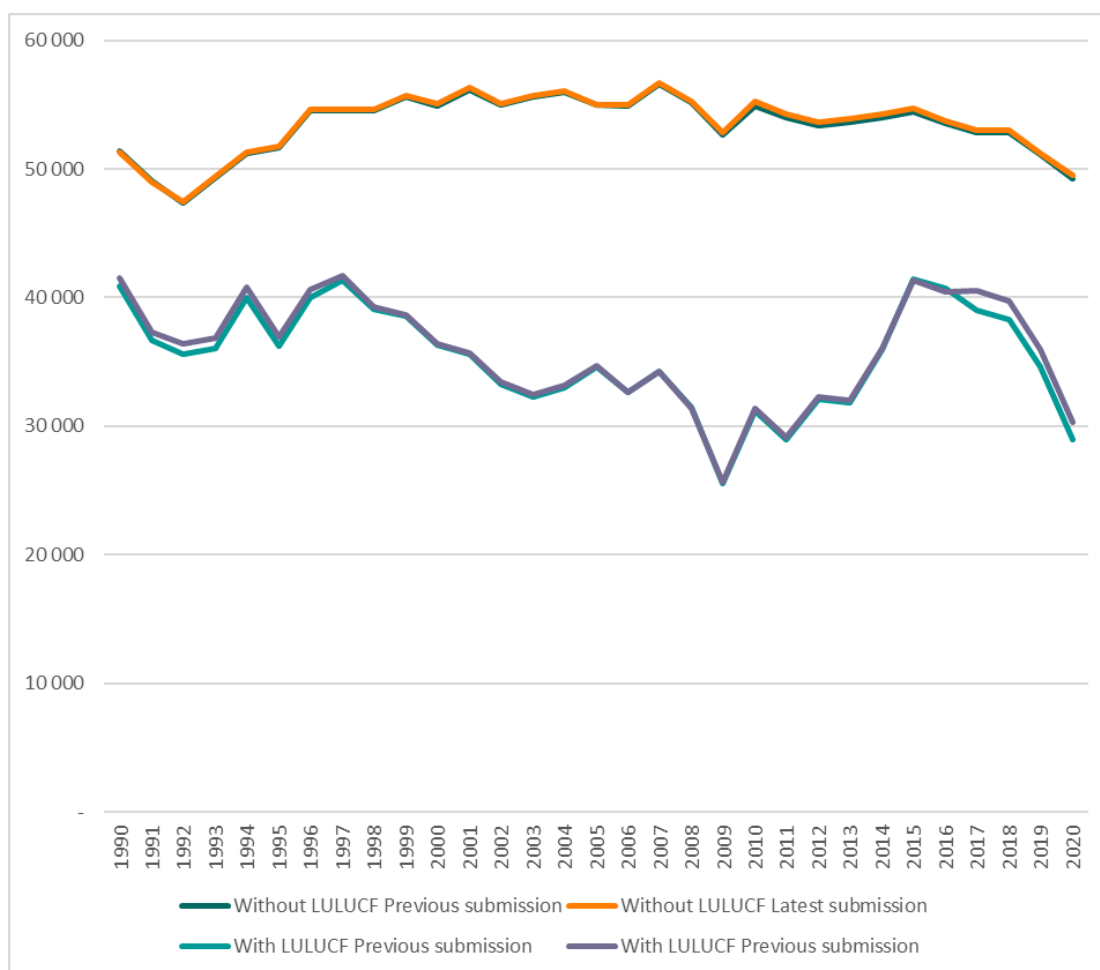


Figure 10-2 Total emissions with and without LULUCF. Previous and latest submission. 1000 tonnes CO<sub>2</sub> equivalents

| <b>Table10-41 Total emissions with and without LULUCF for 1990 and 2020. Previous and latest submission. 1000 tonnes CO<sub>2</sub> equivalents and per cent.</b> |                     |                   |                                  |                     |                   |                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-------------------|----------------------------------|---------------------|-------------------|----------------------------------|
|                                                                                                                                                                   | Without LULUCF      |                   |                                  | With LULUCF         |                   |                                  |
|                                                                                                                                                                   | Previous submission | Latest submission | Difference due to recalculations | Previous submission | Latest submission | Difference due to recalculations |
| <b>Emissions 1990</b>                                                                                                                                             | 51 432              | 51 305            | -127                             | 40 890              | 41 477            | 587                              |
| <b>Emissions 2020</b>                                                                                                                                             | 49 273              | 49 498            | 225                              | 28 940              | 30325             | 1 385                            |
| <b>Trend ktonnes</b>                                                                                                                                              | -2 159              | 1 807             | 352                              | -11 950             | -11 152           | 798                              |
| <b>Trend per cent</b>                                                                                                                                             | -4.2                | -3.5              | 0.7                              | -29.2               | -26.9             | 2.3                              |

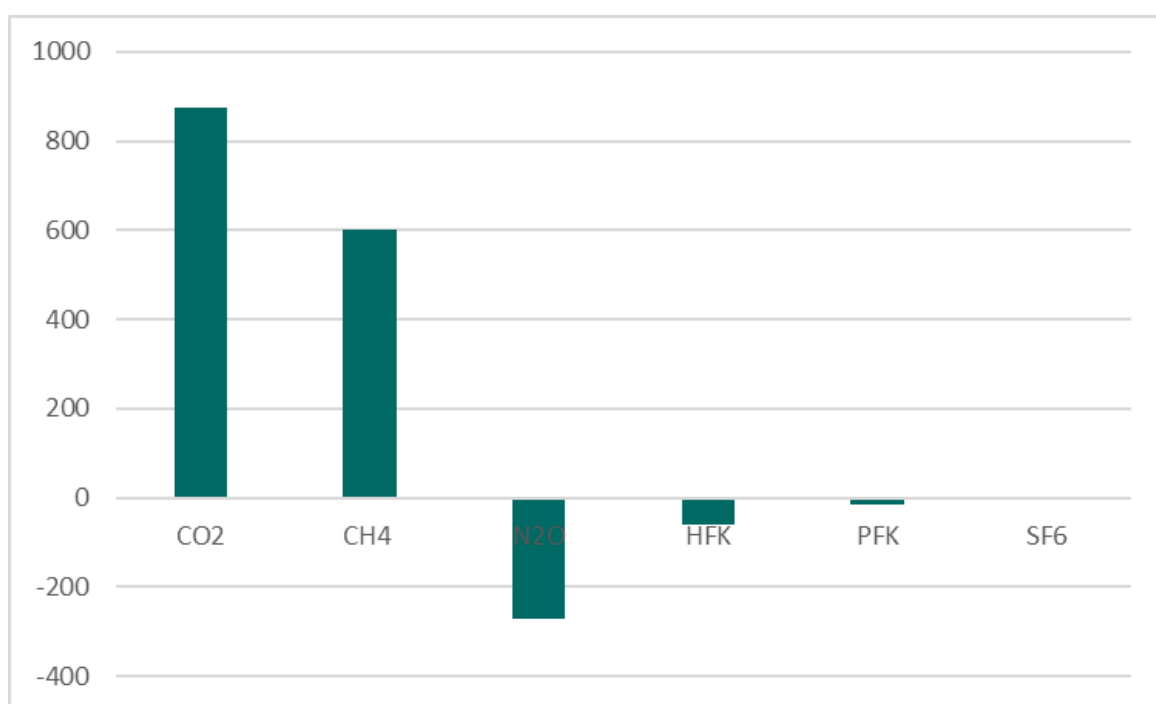


Figure 10-3 Difference in total emissions for 2020 per gas, excluding LULUCF, between latest and previous submission. 1000 tonnes CO<sub>2</sub> equivalents

## 10.4 Implemented and planned improvements in response to the review process

The Norwegian Environment Agency co-ordinates the development and improvements of the inventory's different sectors. The recommendations from the review process are recorded in a spread sheet together with the needs recognized by the Norwegian inventory experts to form an annual inventory improvement plan. Needs identified by use of the data for purposes other than reporting are also included. The overall aim of inventory improvement is to improve the accuracy and reduce uncertainties associated with the national inventory estimates. Each issue is assigned to a sector/theme and the overview tracks where the issue has originated from and the organization/person responsible for following up the recommendations. The overview is discussed by the institutions in the national inventory system and each issue is given a priority and a deadline. All three institutions in the national inventory system therefore have a shared responsibility for the development of the inventory. The issues are prioritized based on the recommendations from the ERT and available human and financial resources. The national greenhouse gas inventory has undergone substantial improvements over the years, and the inventory is considered to be largely complete and transparent.

The status of implementation of the recommendations given in the most recently published UNFCCC review report is given in [Table 10-42](#). The latest report (ARR2022) is not published at the time of reporting; however, the results are mostly ready and have been communicated to the Norwegian inventory team. This report will summarize the findings from the review in 2022 and unresolved issues from earlier reviews.

**Table10-42 Implemented and planned improvements in response to the review process**

| CRF category / issue                                                                           | Review recommendation                                                                                                                                                                                                                                                                                                       | Review report* and paragraph                 | MS response / status of implementation                                                                                             |  | Chapter/section in the NIR  |
|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|--|-----------------------------|
| <b>General, indirect emissions</b>                                                             | Report in the CRF tables and in the NIR the national totals with and without indirect CO <sub>2</sub> emissions in line with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines, making relevant changes to the sectoral level reporting, as necessary (see document FCCC/ARR/2020/NOR, ID#s E.28 and I.11). | ARR/2022 G.1 (ARR/2020 G.13)                 | Addressed. Indirect CO <sub>2</sub> -emissions have been reallocated in the 2023 submission.                                       |  | NIR chapter 2 and 9         |
| <b>General, recalculations</b>                                                                 | The ERT recommends that the Party in its next NIR includes information on its procedures to identify recalculations (including those that change the estimates by less than 2 per cent) and reports these in the NIR, with explanatory information and justifications.                                                      | ARR/2022 G.11                                | Addressed.                                                                                                                         |  | NIR chapter 10.1            |
| <b>1.A.2.a Iron and steel – solid fuels – CO<sub>2</sub></b>                                   | Describe in the NIR the methods, AD and emissions voluntarily reported by the iron and steel industry, and how the Party ensures that a complete and consistent time series of information is reported at the national level for this industry.                                                                             | ARR/2022 E.10 (ARR/2020 E.12, ARR/2018 E.35) | Addressed. Information of method, AD and time series consistency are added in the NIR 2023.                                        |  | Section 3.2.3.2             |
| <b>1.A.2.a Iron and steel – solid fuels – CO<sub>2</sub></b>                                   | Investigate the underlying reason where large inter-annual fluctuations in the CO <sub>2</sub> IEFs are identified to ensure accurate reporting of emissions and describe the reason in the NIR.                                                                                                                            | ARR/2022 E.11 (ARR/2020 E.13, ARR/2018 E.35) | Addressed. Documented in NIR.                                                                                                      |  | Chapter 3.2.2.3 and 3.2.3.4 |
| <b>1.B.2 Oil and natural gas and other – gaseous fuels – CO<sub>2</sub> and CH<sub>4</sub></b> | Report emissions at the level of data entry in CRF table 1.B.2, providing AD and CO <sub>2</sub> and CH <sub>4</sub> emission estimates (or notation keys) for all subcategories, as appropriate.                                                                                                                           | ARR/2022 E.15 (ARR/2020 E.17, ARR/2018E.28,  | Addressing. A new method for venting was implemented in the inventory in the NIR 2020. The documentation in the NIR has since been |  | Section 3.4                 |

**Table10-42 Implemented and planned improvements in response to the review process**

|                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                              |                                                                                                                                                                                                                                                                                                     |                                           |             |
|--------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-------------|
|                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | ARR/2016E.33)                                | improved. Disaggregated data input in the CRF is yet to be implemented.                                                                                                                                                                                                                             |                                           |             |
| <b>1.B.2 Oil, natural gas and other emissions from energy production liquid and gaseous fuels- CH<sub>4</sub> and CO<sub>2</sub></b> | Advance research on fugitive and cold-venting sources from oil and natural gas exploration and production and make further improvements to the data supply and reporting system, where necessary, to enable the Party to significantly improve the level of resolution in the reporting of fugitive, flaring and venting emissions from oil and natural gas systems.                                                                                                                                                                                                                           | ARR/2022 E.16 (ARR/2020 E.18, ARR/2018 E.36) | Addressing. A new method for venting was implemented in the inventory in the NIR 2020. The documentation in the NIR has since been improved. Disaggregated data input in the CRF is yet to be implemented.                                                                                          | Other improvements have been prioritised. | Section 3.4 |
| <b>1.B.2 Oil, natural gas and other emissions from energy production gaseous and liquid fuels- CH<sub>4</sub> and CO<sub>2</sub></b> | Advance the research and make improvements to the data reporting systems used to estimate emissions by subcategory, including from fugitive emissions and from venting and flaring, and include clear justification for the country-specific EFs and methods applied in order to provide evidence of the accuracy and completeness of the time series of emission estimates for all subcategories, including fugitive emissions and venting and flaring. (In particular, the NIR should include a description of the methods used by operators for the facility-level reporting of emissions.) | ARR/2022 E.17 (ARR/2020 E.20, ARR/2018 E.37) | Addressing. A new method for venting was implemented in the inventory in the NIR 2020. The documentation in the NIR has since been improved. Disaggregated data input in the CRF is yet to be implemented.                                                                                          | Other improvements have been prioritised. | Section 3.4 |
| <b>1.B.2 Oil, natural gas and other emissions from energy production gaseous and liquid fuels- CH<sub>4</sub> and CO<sub>2</sub></b> | Present information supporting the EFs, in particular a comparison of country-specific EFs and methods with IPCC default EFs and methods, together with relevant information on, for example, mitigation technologies used in the oil and gas exploration and production sector in the country, and any monitoring of fugitive and venting emissions at oil and gas installations, for CH <sub>4</sub> in particular, in order to provide assurance of the completeness and accuracy of the national inventory.                                                                                | ARR/2022 E.18 (ARR/2020 E.21, ARR/2018 E.37) | Addressing. Comparisons of country-specific EFs and methods with IPCC default EFs for venting and diffuse emissions have been included. Separate comparisons for oil and gas activities are not yet finalised. References providing support for country- and field-specific EFs have been provided. | Other improvements have been prioritised. | Section 3.4 |

**Table10-42 Implemented and planned improvements in response to the review process**

|                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                          |                                                                                                                               |  |                                         |
|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|--|-----------------------------------------|
| <b>Fuel combustion – reference approach – solid fuels CO<sub>2</sub></b>        | Improve the data collection procedures for solid fuels (coal and coke oven coke)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | ARR/2022 E.3 (ARR/2020 E.3, ARR/2018 E.3, ARR/2016 E.4)  | Addressed. The comparison of consumption data with data for imports on an aggregated level is applied in the 2023 submission. |  | Section 3.6.1 and Annex XII chapter 6.3 |
| <b>Fuel combustion – reference approach – solid fuels – CO<sub>2</sub></b>      | Report on the time frame and progress of the revised energy balance system, highlighting the resulting reduction in statistical differences for solid fuels.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ARR/2022 E.4 (ARR/2020 E.4, ARR/2018 E.5, ARR/2016 E.17) | Addressed: Improved data collection and QA/QC-routines are incorporated. Documentation in Annex XII is updated and improved.  |  | Section 3.6.1 and Annex XII             |
| <b>1.A. Fuel combustion – sectoral approach – liquid fuels – CO<sub>2</sub></b> | Initiate a review and evaluation of the downstream oil market and develop and implement a plan to improve the quality of downstream oil supply data for national consumption and sales to the international market, which should include implementing new or improved data supply mechanisms to secure access to required AD, where necessary; conducting research to improve data quality through the comparison of oil product supply data from customs with information received directly from refiners and other suppliers; conducting research to reduce the uncertainty of the allocation of fuels between national navigation and international shipping; and reporting on progress in the NIR. | ARR/2022 E.7 (ARR/2020 E.11, ARR/2018 E.34)              | Addressed. Documented in the annex XII, chapter 6.2.                                                                          |  | Section 3.6.1 and Annex XII             |
| <b>1.B.2.a Oil – liquid fuels – CO<sub>2</sub></b>                              | Improve the QC checks to ensure that information for all recalculations is provided in the NIR, including those linked to the correction of errors, in line with paragraphs 43–45 of the UNFCCC Annex I inventory reporting guidelines.                                                                                                                                                                                                                                                                                                                                                                                                                                                                | ARR/2022 E.20 (ARR/2020 E.24)                            | Addressed. A more systematic routine for reporting on recalculations has been established.                                    |  | Chapters 10 and 3                       |
| <b>1.A Fuel combustion – sectoral approach all fuels – CO<sub>2</sub></b>       | Provide in the NIR an improved discussion of the reliability of the national CO <sub>2</sub> emission estimates for fuel combustion (estimated using the sectoral approach) that better supports the Party's claim of the accuracy                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | ARR/2022 E.9 (ARR/2020 E.26)                             | Addressed: Improved discussion of differences in Annex XII                                                                    |  | Section 3.6.1 and Annex XII             |

**Table10-42 Implemented and planned improvements in response to the review process**

|                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               |                                                                                                                        |             |                                         |
|-------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------|-------------|-----------------------------------------|
|                                                                                                                               | and completeness of reported emissions from fuel combustion (category 1.A).                                                                                                                                                                                                                                                                                                                                                                        |                               |                                                                                                                        |             |                                         |
| <b>1.B Fugitive emissions from fuels - all fuels - CO<sub>2</sub>, CH<sub>4</sub>, NMVOC</b>                                  | Make efforts to report indirect CO <sub>2</sub> emissions in CRF table 6, excluding them from sectoral CRF tables 1.B.1 and 1.B.2.                                                                                                                                                                                                                                                                                                                 | ARR/2022 E.13 (ARR/2020 E.28) | Addressed. Implemented in the 2023 submission.                                                                         |             | Section 3.3.1 and 3.4.1.4               |
| <b>1.A Fuel combustion - sectoral approach - other fossil fuels, biomass - CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O</b> | The ERT recommends that the Party (a) split the AD and CH <sub>4</sub> and N <sub>2</sub> O emissions from the combustion of waste into a fossil component (reported under other fossil fuels) and a biogenic component (reported under biomass) in CRF tables 1.A(a)s1-1.A(a)s2; and (b) calculate and report CO <sub>2</sub> emissions from the biogenic fraction of waste as an information item under biomass in CRF tables 1.A(a)s1-1.A(a)s2. | ARR/2022 E.22                 | Not addressed                                                                                                          | New finding |                                         |
| <b>1.A.1.a</b>                                                                                                                | The ERT recommends that the Party correct the AD for liquid fuels for categories 1.A.1.a.i (electricity generation) and 1.A.1.b (petroleum refining) reported in CRF table 1.A(a)s1 in 2019 and 2020 and check whether the AD correspond to the reported emissions.                                                                                                                                                                                | ARR/2022 E.23                 | Addressing. AD for 2019 and 2020 have been corrected. Correspondence between AD and emissions will be further checked. | New finding |                                         |
| <b>1.A.2.c Chemicals - liquid fuels - CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O</b>                                      | The ERT recommends that the Party correct the AD for liquid fuel consumption for subcategory 1.A.2.c and check that the corrected AD correspond to the reported CO <sub>2</sub> emissions.                                                                                                                                                                                                                                                         | ARR/2022 E.25                 | Addressed. Included in the 2023 submission                                                                             |             | CRF 1A2C liquid                         |
| <b>1.A.2.f Non-metallic minerals - solid fuels - CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O</b>                           | The ERT recommends that the Party reallocate the AD for waste to other fossil fuels (for fossil waste) or to biomass (for biogenic waste).                                                                                                                                                                                                                                                                                                         | ARR/2022 E.26                 | Addressed. Implemented in the 2023 submission.                                                                         |             | CRF, Section 10.2.2 and Section 3.2.3.7 |
| <b>1.A.3.b Road transportation - gasoline, diesel oil- CO<sub>2</sub></b>                                                     | The ERT recommends that the Party determine when and how the country-specific CO <sub>2</sub> EFs for gasoline and diesel oil from the Norwegian pollution control agency 1999 report were derived and either justify that these CO <sub>2</sub> EFs are still valid for the most recent years or revise the EFs across the time series                                                                                                            | ARR/2022 E.27                 | Not addressed                                                                                                          | New finding |                                         |

**Table10-42 Implemented and planned improvements in response to the review process**

|                                                                                                                                                                              |                                                                                                                                                                                                                                                                                             |                              |                                                                                                                           |             |                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------|-------------|--------------------------------------------------------|
| <b>1.A.4.a Commercial/institutional – gaseous fuels – CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O</b>                                                                     | The ERT recommends that the Party correct the activity data and emissions from natural gas under subcategory 1.A.4.a.i stationary combustion (commercial/institutional) for 2019 and 2020.                                                                                                  | ARR/2022 E.28                | Addressed                                                                                                                 |             | CRF 1A4ai gaseous, Section 10.2.2 and section 3.2.10.6 |
| <b>1.A.4.b Residential – biomass – CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O</b>                                                                                        | The ERT recommends that the Party describe in the NIR how time-series consistency is ensured when using three different surveys to compile AD and explain the trend in AD for biomass throughout the time series for subcategory 1.A.4.b.i stationary combustion (residential).             | ARR/2022 E.29                | Addressed. Included in the 2023 submission.                                                                               |             | Section 3.2.10.2, 3.2.3.4                              |
| <b>1.A.4.b Residential – biomass – CH<sub>4</sub></b>                                                                                                                        | The ERT recommends that the Party include in section 3.2.10.3 and/or table 3.6 of the NIR a description of the CH <sub>4</sub> IEF for residential biomass burning for subcategory in 1.A.4.b.i stationary combustion (residential) and explain the trend in the IEF across the time series | ARR/2022 E.30                | Addressed. Included in the 2023 submission.                                                                               |             | Section 3.2.1.3, 3.2.10.2 and 3.2.10.3                 |
| <b>1.B.2 Oil, natural gas and other emissions from energy production – CO<sub>2</sub></b>                                                                                    | The ERT recommends that the Party estimate the missing direct CO <sub>2</sub> emissions for subcategories 1.B.2.a (oil), 1.B.2.b (natural gas) and 1.B.2.c (venting) and report these emissions in CRF table 1.B.2.                                                                         | ARR/2022 E.31                | Not addressed                                                                                                             | New finding |                                                        |
| <b>1.B.2 Oil, natural gas and other emissions from energy production – CO<sub>2</sub> 1.B.2 Oil, natural gas and other emissions from energy production – CH<sub>4</sub></b> | The ERT recommends that the Party recalculate the venting and fugitive CH <sub>4</sub> emissions for subcategory 1.B.2.c.1.iii venting (combined) for 1990–2016 and explain the recalculations in the NIR                                                                                   | ARR/2022 E.32                | Not addressed                                                                                                             | New finding |                                                        |
| <b>2.D Non-energy products from fuels and solvent use – CH<sub>4</sub>, N<sub>2</sub>O</b>                                                                                   | The ERT recommends that the Party apply correct notation keys for recovery of CH <sub>4</sub> and N <sub>2</sub> O for lubricant use and solvent use (categories 2.D.1 and 2.D.3.a) in CRF table 2(l).A-Hs2.                                                                                | ARR/2022 I.6 (ARR/2020 I.15) | Addressing. Notation keys were only changed for 2.D.1. The notation keys for 2.D.3.a were changed in the 2023 submission. |             |                                                        |



**Table10-42 Implemented and planned improvements in response to the review process**

|                                                                 |                                                                                                                                                                                                                                                                                                                                               |                                             |                                                                                                                                                                                                                                                    |                                           |                                                          |
|-----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------------------------------------------------|
| <b>2.E.1 Integrated circuit or semiconductor - SF6</b>          | The ERT recommends that the Party provide further justification for the assumption of constant values for the AD and EF in the NIR and, provided that funding is available and the project is prioritized, report on the use of up-to-date studies and assumptions to estimate SF6 emissions for category 2.E.1.                              | ARR/2022 I.9 (ARR/2020 I.17)                | Addressing. We are seeking to obtain updated information on the use of SF6 in the production of semiconductors in Norway. The results from the mapping will hopefully contribute to better data quality and documentation for this source category | Other improvements have been prioritised. |                                                          |
| <b>2.F.1 Refrigeration and air conditioning - HFC</b>           | The ERT recommends that the Party report more transparently on the inclusion of early decommissioned appliances contributing to HFC-143a emissions from "recovery" and on the use of notation keys in combination with the values reported for the inherently interrelated AD and emissions sources for this category                         | ARR/2022 I.18 (ARR/2020 I.20)               | Addressed IE is implemented as notation key for categories and gases where phasing out occurs, but no recovery is reported.                                                                                                                        |                                           | 4.7.1.                                                   |
| <b>2.F.1 Refrigeration and air conditioning - HFCs and PFCs</b> | "The ERT recommends that Norway implement the identified areas for improvement (e.g. gathering information on recycling rates, including expanding ongoing research and outreach to relevant industry associations on EFs and use practices, use of blends), especially for more significant applications, and report on progress in the NIR. | ARR/2022 I.12 (ARR/2020 I.7, ARR/2018 I.27) | Addressing. Ongoing improvement. New emission factors are implemented, with explanations, for all significant applications. Progress on the remaining sectors are described in the NIR. Remaining recovery rates are under evaluation.             | Other improvements have been prioritised. | 2.F.1 Refrigeration and air conditioning – HFCs and PFCs |
| <b>General</b>                                                  | "The ERT recommends that Norway, in order to improve the comparability and transparency of its reporting, exclude indirect CO <sub>2</sub> emissions from the sectoral (direct) CO <sub>2</sub> emissions in the IPPU sectoral tables and report indirect CO <sub>2</sub> emissions from the IPPU sector in CRF table 6.                      | ARR/2022 I.2 (ARR/2020 I.11)                | Addressed. Is implemented in the CRF for the 2023 reporting and documented in the 2023 NIR.                                                                                                                                                        |                                           | General                                                  |
| <b>2.B.8 Petrochemical and</b>                                  | The ERT recommends that the Party explain in the NIR that the methods for measuring and reporting CH <sub>4</sub>                                                                                                                                                                                                                             | ARR/2022 I.21                               | Addressing. The NIR explains that the method                                                                                                                                                                                                       | New finding.                              | 4.3.6.2                                                  |

**Table10-42 Implemented and planned improvements in response to the review process**

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| <b>carbon black production – CH<sub>4</sub></b>                                      | emissions for methanol production under category 2.B.8 are under revision and the emissions reported for 2016 onward are assumed to be the same as for 2013-2015.                                                                                                                                                                                                                                                                                                                                                                                                           |               | for measuring and reporting CH <sub>4</sub> emissions is under revision. Once the plant's revised method for measuring and reporting fugitive emissions is finalized, it will be considered for implementation in the national GHG inventory. |              |                                              |
| <b>2.C.6 Zinc production – CO<sub>2</sub></b>                                        | The ERT recommends that the Party report the available AD for zinc production in CRF table 2(I).A-Hs2 for the entire time series rather than reporting them as "NE".                                                                                                                                                                                                                                                                                                                                                                                                        | ARR/2022 I.22 | Addressed. AD reported in the 2023 CRF.                                                                                                                                                                                                       |              | NIR section 4.4.5.3 and CRF Table 2(I).A-Hs2 |
| <b>2.D.3 Other (non-energy products from fuels and solvent use) – CO<sub>2</sub></b> | The ERT recommends that the Party include in the NIR a transparent description of any recalculations made for category solvent use, reported under category 2.D.3, including the rationale for the recalculations and information on any AD updates. The ERT also recommends that the Party provide an explanation for the significant interannual changes in CO <sub>2</sub> emissions from solvent use, reported under category 2.D.3, in 2018-2020 (CO <sub>2</sub> emissions were 112.03, 87.73 and 122.15 kt CO <sub>2</sub> eq for 2018, 2019 and 2020 respectively). | ARR/2022 I.23 | Addressed. A description of sensitivity in inter-annual changes in the activity data are included in NIR                                                                                                                                      | New finding. | NIR chapter 4.5.3.2                          |
| <b>2.E Electronics industry – HFCs</b>                                               | The ERT recommends that the Party update the documentation box in CRF table 2(II)B-Hs2, namely, remove the text that states emissions of an unspecified mix of HFCs for subcategories 2.E.1, 2.E.2, 2.E.3 and 2.E.4 are included in the emissions reported for category 2.F                                                                                                                                                                                                                                                                                                 | ARR/2022 I.24 | Addressing.                                                                                                                                                                                                                                   | New finding. | CRF Table 2(II)B-Hs2                         |
| <b>2.F.1 Refrigeration and air conditioning – HFCs</b>                               | The ERT recommends that the Party explain in the NIR that the 95.5 per cent decrease in HFC emissions from industrial refrigeration (a subcategory under 2.F.1) between 2019 and 2020 is due to a drop in HFC imports in 2003, which resulted from the introduction of a tax aimed at stimulating a reduction in the use of HFCs, combined with an assumed lifetime of 17 years for industrial refrigeration equipment.                                                                                                                                                     | ARR/2022 I.25 | Addressed An explanation is included in NIR                                                                                                                                                                                                   | New finding. | CRF table 2(II)B-Hs2 and section 4.7.1.1     |

**Table10-42 Implemented and planned improvements in response to the review process**

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| <b>3.A Enteric fermentation – CH<sub>4</sub></b> | The Party reported the weight and typical animal mass for sheep, swine, deer, goats, horses, poultry, reindeer and fur-bearing animals as "NE" in CRF tables 3.As2 (additional information for enteric fermentation) and 3.B(b) (for N <sub>2</sub> O emissions from manure management). During the review, the Party clarified that the typical animal mass is reported as "NE" because this variable is not used in the method applied for estimating those emissions for these livestock types in the Norwegian inventory. The ERT noted that the weight and typical animal mass could help improve comparability across Parties, even if the parameter is not used in the estimations.                                                                                                                                                                                                         | ARR/2022 A.1 | Addressed. Notation keys are changed to NA in the 2023 CRF. |  |  |
| <b>3.B Manure management – N<sub>2</sub>O</b>    | The Party reported average GE (MJ/head/day) and average Ym for swine, deer, goats, horses, poultry, reindeer and fur-bearing animals as "NE" in CRF table 3.As1. During the review, the Party clarified that these parameters are reported as "NE" because they are not used in the tier 1 method applied for estimating enteric CH <sub>4</sub> emissions for these livestock types in the Norwegian inventory. The Party indicated that the notation key can be changed to "NA" in the 2023 submission if the ERT recommends this as a more appropriate notation key. The ERT recommends that the Party report average GE and average Ym for swine, deer, goats, horses, poultry, reindeer and fur-bearing animals or use "NA" in CRF table 3.As1 if it does not use these parameters in the estimation of emissions from enteric fermentation and explain in the NIR the reason for using "NA". | ARR/2022 A.2 | Addressed. Notation keys are changed in the 2023 CRF.       |  |  |
| <b>3.A Enteric fermentation – CH<sub>4</sub></b> | The Party reported many parameters for growing cattle, mature dairy cattle, other mature cattle, sheep and swine as "NE" in CRF table 3.As2. During the review, the Party clarified that these parameters are reported as "NE" because they are not used in the method applied for estimating enteric CH <sub>4</sub> emissions for these livestock types in the Norwegian inventory.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | ARR/2022 A.3 | Addressed. Notation keys are changed in the 2023 CRF.       |  |  |

**Table10-42 Implemented and planned improvements in response to the review process**

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|                                               | The ERT encourages the Party to report the parameters for growing cattle, mature dairy cattle, other mature cattle, sheep and swine as "NA" in CRF table 3.As2 if it does not use a tier 2 methodology to estimate the emissions from enteric fermentation for those livestock types and to explain in the NIR the reason for using "NA".                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |              |                                                        |  |  |
| <b>3.B Manure management - N<sub>2</sub>O</b> | The Party reported N <sub>2</sub> O emissions from manure management in CRF table 3.B(b). The ERT noted that the total N excreted for the category "growing cattle" from all MMS for 2020 (23,517,221 kg N) is about 75,000 kg N/year higher than the total N excreted calculated from population size (526,905 animal years in 2020) multiplied by Nex rate per animal year (44.49 kg N/animal year), which equals 23,441,676 kg N. Differences also occur for other years, but in the opposite direction, that is, total N excreted from all MMS is lower than the total calculated from population size. For example, for 2019, the difference is -13,711 kg N/year; for 2018, -630 kg N/year; for 2017, -7,646 kg N/year; for 2016, -9,788 kg N/year; for 2015, -7,369 kg N/year; and for 2014, -6,111 kg N/year. Differences also occur for the categories "mature dairy cattle" and "sheep". The total N excreted for "mature dairy cattle" from all MMS for 2019 (26,523,651 kg N) is about 15,900 kg N/year lower than the total N excreted calculated from population size (199,417 head in 2019) multiplied by Nex rate per head (132.93 kg N/head), which equals 26,507,738 kg N. The total N excreted for the category "sheep" from all MMS for 2018 (13,514,864 kg N) is 53,714 kg N/year lower than the total N excreted calculated from population size (1,409,143 animal years in 2019) multiplied by Nex rate per head (9.63 kg N/head), which equals 13,568,578 kg N. The total N excreted from all MMS for "sheep" for 2019 is 2,239 kg N/year higher than the total N excreted calculated from population size. During the review, the Party clarified that the value of 44.49 kg/animal year reported as the Nex rate in CRF table 3.B(b) does not correspond to the | ARR/2022 A.4 | Addressed. This is correctly reported in the 2023 CRF. |  |  |

**Table10-42 Implemented and planned improvements in response to the review process**

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|                                               | <p>value for total N excreted. The correct value is 44.69 kg N/head. The reason for the difference is that these two values, Nex rate and total N excreted, are updated at different times and not fully in coordination. Population figures and total N excreted are automatically calculated by CRF Reporter but the Nex rate is manually updated. This lack of harmonization does not, however, affect the emissions of N<sub>2</sub>O reported in CRF table 3.B(b). These emissions are correct because the Party has estimated them using a higher level of disaggregation of livestock categorization for growing cattle in the inventory than the disaggregation applied in the CRF table. The aggregated manually updated Nex rate for growing cattle is calculated separately only for use as additional information in the CRF reporting - it is not used in the inventory estimations. A harmonized table for Nex rate (kg/head/year) and total N excreted will be reported in the next annual submission. The ERT recommends that the Party report consistent values for total N excreted for growing cattle (from 2014 onward), mature dairy cattle (for 2019) and sheep (for 2018 and 2019) in CRF table 3.B(b) by ensuring that the values for total calculated from all MMS and total calculated from population size and Nex rate are the same. The ERT also recommends that the Party implement QA/QC checks for ensuring the consistency of these values for all years in the time series.</p> |              |                                                       |  |                               |
| <b>3.B Manure management – CH<sub>4</sub></b> | <p>The Party reported in its NIR (p.5-31) that the MCFs for storage of solid manure (deep litter and solid manure) are based on default IPCC factors. The ERT noted that MCFs for storage of solid manure and dry lot presented in NIR table 5.14 and CRF table 3.b(a)s2 (e.g. mature dairy cattle, 8.1 per cent; mature non-dairy cattle, 10.3 per cent; young cattle/growing cattle, 10.0 per cent; sheep, 11.1 per cent; goats, 13.2 per cent; swine, 7.4 per cent) are higher than the default values in the 2006 IPCC Guidelines (vol. 4, table 10.17), which are 2.0 per cent for solid storage and 1.0 per cent for dry lot. During the review, the Party clarified that the reference given on</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ARR/2022 A.5 | Addressed. Implemented in the UNFCCC submission 2023. |  | NIR 2023, Chapter 5.3.1.1.1.1 |

**Table10-42 Implemented and planned improvements in response to the review process**

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|                                               | <p>page 5-31 of the NIR is not correct. The MCFs for storage of solid manure (deep litter and solid manure) consider the default IPCC factors and a methodology from the 2019 Refinement to the 2006 IPCC Guidelines. The relevant text in the NIR will be corrected in the 2023 submission. The Party indicated that detailed documentation of the Norwegian model used for estimating CH<sub>4</sub> emissions from manure management and a description of how the MCFs have been calculated can be found in the report Greenhouse gas emissions from biogas production from manure in Norwegian agriculture of the Norwegian Environment Agency published in 2020. The ERT recommends that the Party correct the reference given in the NIR (p.5-31) to the source of the values for MCFs of storage of solid manure and deep litter to indicate that they are based on default factors and a methodology from the 2019 Refinement to the 2006 IPCC Guidelines (vol.4, chap.10, table 10.17).</p>                                                                                                                              |              |                                                       |  |                               |
| <b>3.B Manure management – CH<sub>4</sub></b> | <p>The Party reported inconsistent MCFs for pasture range and paddock in NIR table 5.14 and CRF table 3.B(a)s2 (0.50 and 0.47 per cent respectively). In addition, the ERT noted that none of the values is in accordance with the 2006 IPCC Guidelines (vol. 4, chap.10, table 10.17), in which the MCF for pasture range and paddock for cold climate is 1 per cent. During the review, the Party clarified that it used the MCF from the 2019 Refinement to the 2006 IPCC Guidelines (vol. 4, chap.10, table 10.17), 0.47 per cent, and that the methodology was documented in the 2020 NIR (p.5-33 and sections 5.5.4 and 10.2.3). Emissions from grazing were estimated under separate MMS categories for all animal categories taking into account the conclusion from Cai et al. (2017) that indicates that there is no significant difference in emission values for different animal categories regardless of the method of representing methane emissions or the climate zone. Thus, the Party used a single set of MCF factors to all animal categories. The ERT recommends that the Party explain in the NIR that</p> | ARR/2022 A.6 | Addressed. Implemented in the UNFCCC submission 2023. |  | NIR 2023, Chapter 5.3.1.1.1.1 |

**Table10-42 Implemented and planned improvements in response to the review process**

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|                                                                                    | the source of the values for MCF for pasture range and paddock is the 2019 Refinement to the 2006 IPCC Guidelines (vol. 4, ch.10, table 10.17), justify why those values are more appropriate to its national circumstances than the values in the 2006 IPCC Guidelines and report consistent values in NIR table 5.14 and CRF table 3.B(a)s2.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |              |                                                       |  |                         |
| <b>3.F Field burning of agricultural residues – CH<sub>4</sub>, N<sub>2</sub>O</b> | The Party reported in NIR table 5.1 that emissions from the field burning of agricultural residues have decreased by 89 per cent since 1990. However, the NIR contains no explanation on this trend. In the NIR the Party explains that the data for the category is provided by Statistics Norway and the Norwegian Crop Research Institute (NIR section 5.5.1.2). During the review, the Party clarified that the amount of crop residues burned in Norway was investigated through surveys conducted in 2004 and 2012. The results of the 2012 survey necessitated the fraction burned for 2011 being reduced to 4 per cent. The reason for the reduction is that with the introduction of grants for changing tillage practices (under Norway's Regional Environment Programme), the burning of straw was prohibited or straw was only allowed to be burned in the spring. Many municipalities have also banned the burning of straw; in these cases, farmers must request and obtain an exception before they are allowed to burn crop residues. The ERT recommends that the Party explain in the NIR the AD used across the time series, including information on the surveys conducted in 2004 and 2012, and explain the trend in emissions for this category, e.g. by describing the introduction of grants for changing tillage practices and the prohibition of or restrictions on the burning of straw. | ARR/2022 A.7 | Addressed. Implemented in the UNFCCC submission 2023. |  | NIR 2023, Chapter 5.5.1 |
| <b>3.F.1 Cereals - CH<sub>4</sub> and N<sub>2</sub>O</b>                           | For wheat, a category under 3.F.1 cereals, the Party reported area burned, biomass available and combustion factor as "NE" in CRF table 3.F. However, total biomass burned and CH <sub>4</sub> and N <sub>2</sub> O emissions were estimated and reported. During the review, the Party                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | ARR/2022 A.8 | Addressed. Notation keys are changed in the 2023 CRF. |  |                         |

**Table10-42 Implemented and planned improvements in response to the review process**

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|                                                                                    | clarified that area burned, biomass available and combustion factor were reported as "NE" in the CRF table because these variables are not used in the method applied for calculating the total amount of biomass burned in the Norwegian inventory. Total biomass burned is estimated using statistics for crop production (in tonnes) and values for dry matter (fraction of crop residue and fraction burned in fields). The ERT recommends that the Party report the area burned, biomass available and combustion factor as "NA" in CRF table 3.F if it does not use these parameters in the estimation of emissions from the field burning of agricultural residues and explain in the NIR the reason for using "NA". |                                              |                                                                                                                                                                                                                                             |                    |             |
| <b>4.A.1 Forest land remaining forest land - CO<sub>2</sub> and N<sub>2</sub>O</b> | Verify the Yasso07 outputs using independent estimates. (Verification could entail collecting a time series of data on SOC content in a subset of national forestry inventory plots representative of countrywide variability of the SOC dynamic in forest land.)                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ARR 2022 L.11 (ARR/2020 L.15, ARR/2018 L.17) | Addressing. Norway is currently preparing methods and infrastructure to start a national level soil carbon monitoring program with the first planned sampling in the NFI grid to start in 2023.                                             |                    |             |
| <b>4.A.1 Forest land remaining forest land - CO<sub>2</sub> and N<sub>2</sub>O</b> | Pending the start of additional data collection, apply alternative means of verification, such as chronosequences stratified by climate, topography, soil and forest type and derived from available data (e.g. International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, Forest Level I) and data from other countries considered representative of conditions in Norway (e.g. Sweden).                                                                                                                                                                                                                                                                                       | ARR 2022 L.12 (ARR/2020 L.16, ARR/2018 L.17) | Addressing. A project has been described to use current base line soil C data on existing experimental sites to establish a dataset for soil C changes in selected forest types and regions. Norway is working on funding for this project. |                    |             |
| <b>4.A.1 Forest land remaining forest land - CO<sub>2</sub> and N<sub>2</sub>O</b> | The ERT recommends that the Party estimate CSC for DOM and SOC under forest land remaining forest land using a more appropriate approach than the currently applied tier 3 approach with the model Yasso07, until                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ARR/2022 L.23                                | Addressing. Norway is working on verification and further documentation.                                                                                                                                                                    | New recommendation | Ch. 6.4.1.3 |



**Table10-42 Implemented and planned improvements in response to the review process**

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|                                                                                             | verification of the Yasso07 model outputs based on the national soil carbon monitoring program or other sound verification is made in accordance with 2006 IPCC guidelines on verification (vol. 1, ch. 6.10). The ERT, noting that during the review the Party provided valid arguments (which are not included in the NIR) against applying a tier 1 approach (the default method for pools in equilibrium), considers that an alternative, more appropriate approach could therefore be the application of a tier 2 method. The ERT notes that, alternatively, the application of one kind of sound verification procedure (independent estimates or alternative means) would be sufficient to resolve this issue as well as ID#s L.11 and L.12 in table 3. |                                                                          |                                                                             |                                                                                                                        |          |
| <b>5.A.1 Managed waste disposal sites – CH<sub>4</sub> Completeness</b>                     | Include the missing emissions attributed to the management of demolition and construction waste or demonstrate that these emissions are insignificant in accordance with decision 24/CP.19, annex I, paragraph 37(b).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | ARR/2022 W.3 (ARR/2020W.2, ARR/2018 W.14)                                | Addressed. A description with the result of the investigations is included. |                                                                                                                        | 7.2.1.3. |
| <b>5.B Biological treatment of solid waste – CH<sub>4</sub> and N<sub>2</sub>O Accuracy</b> | Apply, in line with the 2006 IPCC Guidelines, the tier 2 method, using country-specific EFs, to estimate CH <sub>4</sub> and N <sub>2</sub> O emissions from the biological treatment of solid waste.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | ARR/2022 W.4 (ARR/2020W.3, ARR/2018 W.15)                                | Addressing.                                                                 | Norway has collected AD from the plants but do not have a better EF than the Tier 1 EF provided by the guidelines yet. | 7.4.1.8. |
| <b>5.D.2 Industrial wastewater – N<sub>2</sub>O Transparency</b>                            | Provide in the NIR information consistent with decision 24/CP.19, annex I, paragraph 37(b), to demonstrate the insignificance of N <sub>2</sub> O emissions from industrial wastewater.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | ARR/2022 W.5 (ARR/2020 W.5, ARR/2015 W.11, ARR/2016 W.11, ARR/2018 W.12) | Addressed                                                                   |                                                                                                                        |          |

**Table10-42 Implemented and planned improvements in response to the review process**

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| <b>5.D.2 Industrial wastewater – N<sub>2</sub>O Completeness</b> | Report N <sub>2</sub> O emissions from the industrial wastewater treated in domestic wastewater treatment plants.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ARR/2022 W.7 (ARR/2020 W.6, ARR/2018 W.17) | Addressed. Information provided during the review has been added in the NIR 2019, chapter 7.6.4. | Emissions will be included in the next submission in 5D1 | 7.6.4 |
| <b>5.B Biological treatment of solid waste – CH<sub>4</sub></b>  | The Party reported in its NIR (p. 7-17) that activity data for the previous year, 2020, have been updated because the Norwegian waste accounts has not released updated figures in time for the emission inventory calculations. During the review, the Party clarified that is a mistake and it should be written 2019. The ERT encourages the Party to enhance its QA&QC process to improve the quality of NIR.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ARR/2022 W.8                               | Not addressed                                                                                    | New finding.                                             |       |
| <b>5.B Biological treatment of solid waste</b>                   | "The Party reported in its NIR (p. 7-9 and 7-15) table 7.2 that the activity data were reported as same as previous year (2019) because the activity data have not been updated. This may cause big uncertainty for calculation. But the amount of anaerobic digestion wastewater, of 2020 were provided in the NIR table 7.5. During the review, the Party clarified that in the waste sector, the activity data are collected from different data sources with different accessibility. On one hand, amounts of composted waste and solid waste, used for the biological treatment of waste, are extracted from the Norwegian waste accounts. The waste account is published yearly in December and cannot be available in time for the emission calculations. Activity from the year before is hence used to estimate emissions from the latest year. Activity data related to wastewater are on the other hand collected from other sources and are available at an earlier time and can be used to estimate emissions from the latest year. It is unfortunately not possible for Norway to get activity data about amounts of composted waste and solid waste used for the biological treatment of waste early enough to include this data to estimate emissions from the latest year. | ARR/2022 W.9                               | Not addressed                                                                                    | New finding.                                             |       |

\*The report from the 2022 review has not yet been published at the time of reporting. Thus, there may be small inconsistencies between the text here and in the review report as it is published.

## 11. References

- Add Novatech AS (2016a): Cold venting and Fugitive Emissions from Norwegian Offshore Oil and Gas Activities - Module 3A report - Best available technique (BAT) assessments. , M-665/2016.: Norwegian Environment Agency.
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The Norwegian Environment Agency is a government agency under the Ministry of Climate and Environment.

We work for a clean and diverse environment. Our primary tasks are to reduce greenhouse gas emissions, manage Norwegian nature and prevent pollution.