Norwegian Environment Agency

Greenhouse Gas Emissions 1990-2022

National Inventory Report

Report

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Colophon

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Preface

This document is Norway's National Inventory Report for the year 2024. It serves as the documentation of Norway's greenhouse gas (GHG) inventory under the United Nations Framework Convention on Climate Change (UNFCCC).

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 supplemented by aspects of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 IPCC Refinement), and the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2013 Wetlands Supplement). As recommended by the IPCC Guidelines, country specific methods have been used where appropriate.

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 all information regarding Land Use, Land Use Change and Forestry.

Oslo, March 2024

Siri Sorteberg
Director, Department of Climate
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1. Annexes to NIR

ES. Executive Summary

ES.1 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 1990-2022.

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 supplemented by aspects of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019), and the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014). 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_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). Norway does not have any emissions of nitrogen trifluoride (NF_3) to report. In addition, the inventory includes calculations of emissions of the precursors NO_x, NMVOC, and CO, as well as SO_2. Indirect CO_2 emissions originating from the fossil part of CH_4 and NMVOC are calculated and reported.

Aggregated emissions and removals of greenhouse gases expressed in CO_2 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.

ES.2 Summary of trends related to national emissions and removals

In 2022, total greenhouse gas (GHG) emissions in Norway were 48.9 million tonnes of carbon dioxide equivalents, which is a decrease of 0.4 million tonnes compared to 2021. Emissions reached their peak at 56.4 million tonnes in 2007. They have since decreased by 13%, and were in 2022 2.4 million tonnes, or 4.6%, lower than in 1990.

The net GHG emissions, including all sources and sinks, were 35.1 million tonnes of CO_2 equivalents in 2022, a decrease of 11% 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 13.7 million tonnes CO_2 equivalents in 2022. Forest land was the major contributor to the net sequestration of CO_2 in the sector. In 2022, the total net removals from forest land were 17.9 million tonnes of CO_2 equivalents.

In 2022, CO_2 contributed to 83.7% of the total emission figures, while methane and nitrous oxide contributed to 10% and 4%, respectively. PFCs, HFCs and SF_6 together accounted for 2% of the total GHG emissions.

ES.3 Overview of source and sink category emission estimates and trends

Figure ES.1 shows the overall trend in the total emissions by gas for the period 1990-2022. The most important sector in Norway, with regards to the emissions of greenhouse gases (GHG), is the energy sector, accounting for 68.2% of the total Norwegian emissions. The major sources of emissions within the energy sector are oil and gas extraction and transport.

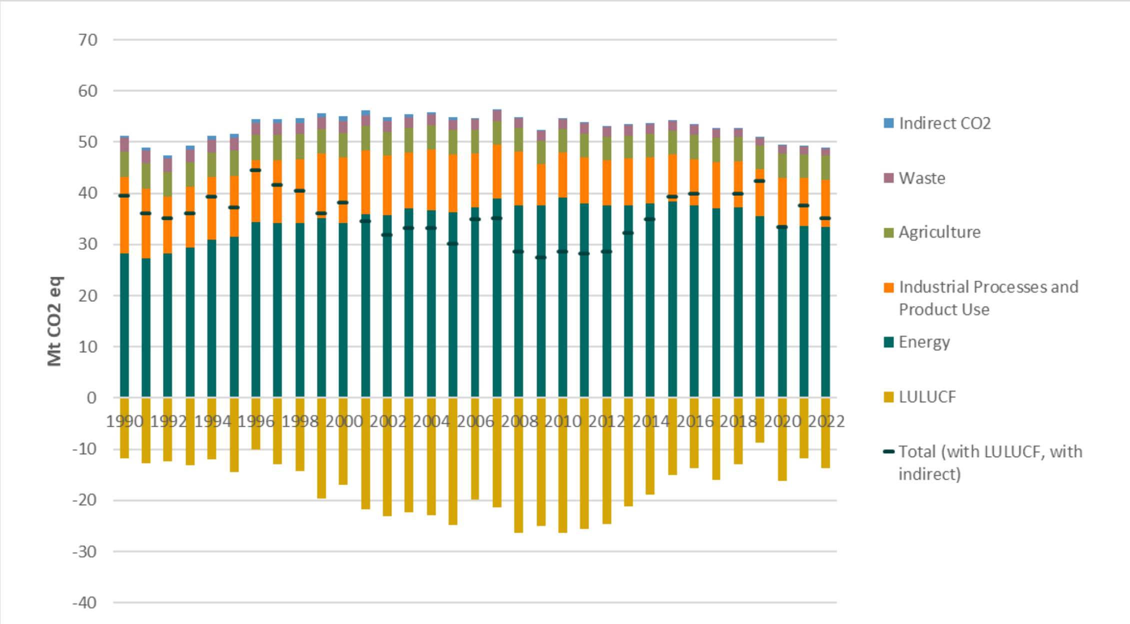

Figure ES.1: Total emissions of greenhouse gases by sources, and removals from LULUCF in Norway, 1990-2022 (Mtonnes CO_2 equivalents). Source: Statistics Norway/Norwegian Environment Agency/Norwegian Institute of Bioeconomy Research.

Figure ES.3 shows the percentage change in emissions of greenhouse gases from 1990 to 2022 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_2 emissions from energy use, both in energy industries and transport. Looking at the overall trend from 1990 to 2022, emissions from the energy sector increased by 18%.

Emissions from transport showed an overall increase of 28% from 1990 to 2022. The share of transport in the total GHG emissions has increased from 19% in 1990 to 26% in 2022. Road transportation accounted for 68% of emissions from the transport sub-sector, while emissions from navigation and civil aviation accounted for 23% and 8%, 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 19% of the total national emissions of greenhouse gases in 2022. Production of metals and chemicals are the main sources of process-related industrial emissions of both CO_2 and other greenhouse gases such as N_2O (fertilizer production) and PFCs (aluminium production). Between 1990 and 2022, emissions from industrial processes decreased by 37%. This is mainly due to reduced PFC emissions from the production of aluminium and SF_6 from the production of magnesium.

The agricultural sector contributed in 2022 to 9.5% of the total emissions of greenhouse gases, with its 4.6 million tonnes CO_2 equivalents. Emissions from agriculture decreased by 2.3% between 2021 and 2022 and decreased by 6.8% between 1990 and 2022. The dominant sources of GHGs are enteric fermentation (CH_4) from domestic animals and agricultural soils (N_2O). These sources contributed to about 52% and 33% to the sector's emissions, respectively.

The waste sector contributed to 2.9% of total Norwegian greenhouse gas emissions in 2022. GHG emissions from the waste sector have generally decreased since 1990, and in 2022, they were 46% 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.

Figure ES.2 shows the various IPCC sectors' share of the total greenhouse gas emissions in Norway in 2022.

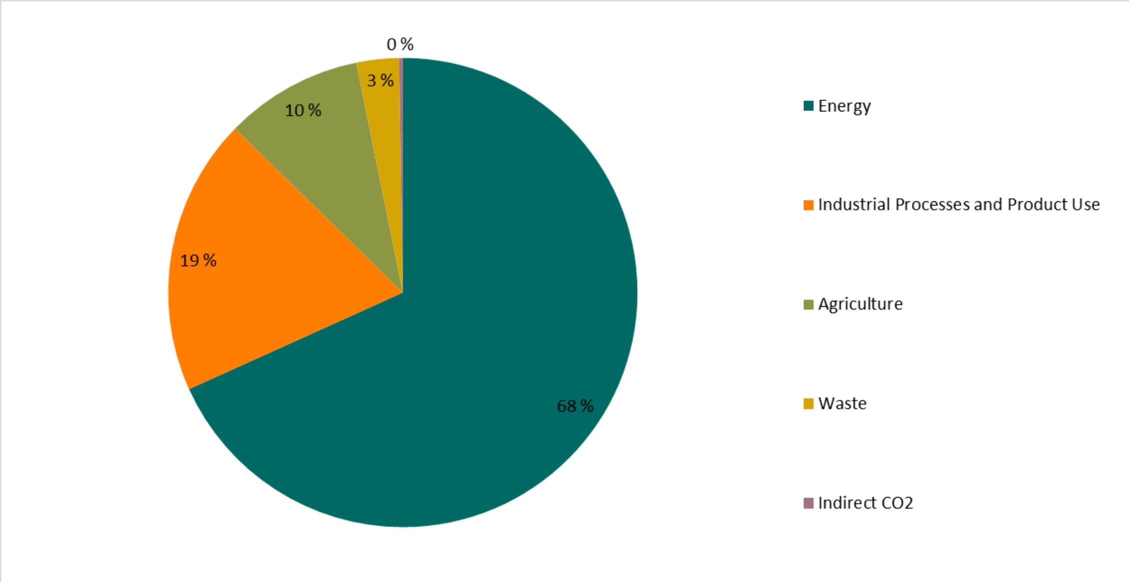

Figure ES.2: Emissions by IPCC sector in 2022, excluding LULUCF. Source: Statistics Norway/Norwegian Environment Agency.

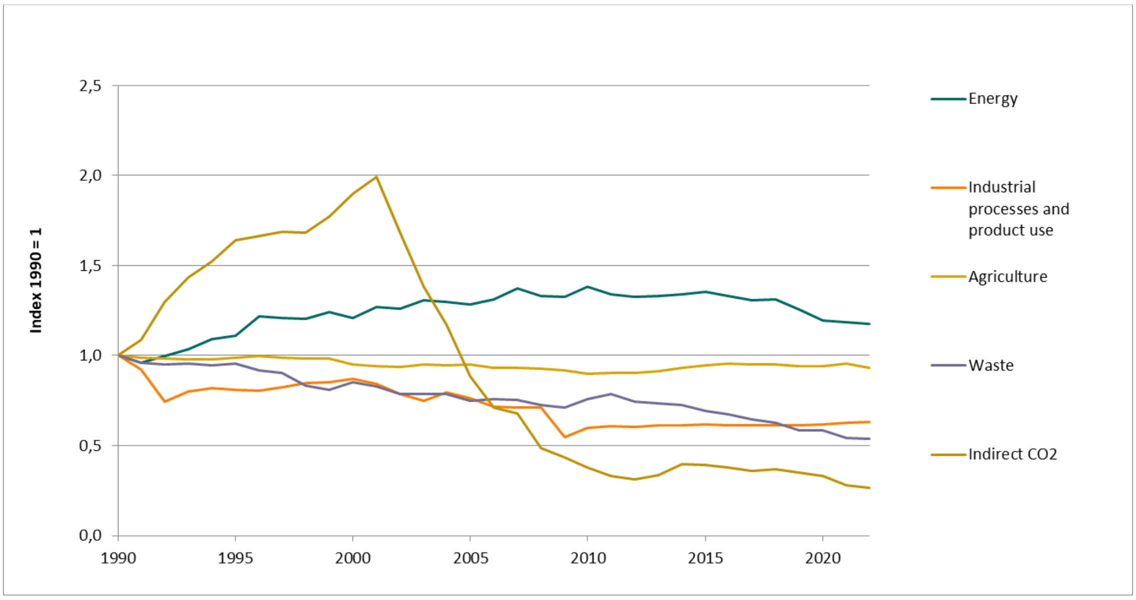

Figure ES.3: Changes in GHG emissions, relative to 1990, by IPCC sector 1990-2022. Index 1990 = 1. Source: Statistics Norway/Norwegian Environment Agency.

The proportion of CO_2 emissions of the national total greenhouse gas emissions has increased from about 68.2% in 1990 to 82.7% in 2022. The increased proportion of CO_2 relative to other gases is due to growth in the CO_2 emissions during this period, as well as a reduction in emissions of N_2O, PFCs and SF_6 gases because of implemented environmental measures and/or technological improvements and closures of industrial plants.

Table ES-1: Emissions of greenhouse gases in Norway during the period 1990-2022. Units: CO_2 in million tonnes (Mt), CH_4 and N_2O in 1000 tonnes (kt) and other gases in 1000 tonnes CO_2 eq. (kt CO_2 eq.).

Gas	CO_2	CH_4	N_2O	PFC	SF_6	HFC
Year	**Mt**	**kt**		**kt CO2 eq**		
1990	35.0	242.3	14.4	3499.8	2163.0	0.0
1995	38.5	249.5	13.0	2078.9	597.6	92.5
2000	42.1	239.3	13.4	1364.1	918.6	359.8
2005	43.3	217.1	14.2	858.2	305.9	521.8
2010	45.6	206.1	8.7	214.3	70.5	761.1
2011	44.7	200.6	8.8	236.1	55.1	822.6
2012	44.2	196.9	8.8	180.3	54.1	869.4
2013	44.5	194.5	8.7	162.8	56.9	925.8
2014	45.0	192.8	8.8	160.9	50.1	914.1
2015	45.5	192.5	8.9	131.6	69.4	871.6
2016	44.7	191.4	8.7	167.4	62.8	878.9
2017	44.2	188.3	8.4	117.8	57.7	893.7
2018	44.4	185.3	8.4	133.1	55.2	833.9
2019	42.8	177.4	8.5	157.4	69.8	831.0
2020	41.2	178.0	8.4	145.2	75.7	776.0
2021	41.0	177.5	8.4	222.8	71.9	743.2
2022	40.8	175.8	8.3	122.2	70.9	746.8

Source: Statistics Norway/Norwegian Environment Agency

Table ES- 2: Emissions in million tonnes CO_2 equivalents in 1990, 2021, 2022, and changes (%) between 1990-2022 and 2021-2022 (without LULUCF).

Year	CO_2	CH_4	N_2O	PFCs	SF_6	HFCs	Total with indirect CO_2 and without LULUCF
1990	35.0	6.8	3.8	3.5	2.2	0.00005	51.3
2021	41.0	5.0	2.2	0.2	0.1	0.7	49.3
2022	40.8	4.9	2.2	0.1	0.1	0.7	48.9
Changes 1990-2022	16.6%	-27.5%	-42.0%	-96.5%	-96.7%	1503091.8 %	-4.6%
Changes 2021-2022	-0.5%	-1.0%	-0.4%	-45.1%	-1.4%	0.5%	-0.8%

Source: Statistics Norway/Norwegian Environment Agency

In 2022, 57% of the methane emissions originated from agriculture, 19% from the energy sector and 24% from the waste sector. The total methane emissions decreased by 1% from 2021 to 2022.

In 2022, agriculture contributed to 77% of the total N_2O emissions. Industrial processes (almost entirely from fertilizer and nitric acid production) was the second biggest contributor, with 11%. The energy sector accounted for 9.2% of the N_2O emissions in 2022, and the waste sector for 2.6%. Due to technical improvements in production of nitric acid, and despite the increased production, the total emissions of N_2O have decreased by 42% since 1990.

The PFC emissions went down by 45% from 2021 to 2022. The emissions have, in total, been reduced by 96.5% since 1990. In 2022, the only source of PFC emissions is aluminium production (perfluorcarbons tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6)), where technical measures have been undertaken to reduce emissions. CO_2 emissions from aluminium production have increased since 1990 due to increased production levels. There were minor emissions of octafluoropropane (C_3F_8) from refrigeration in 2010-2014.

SF_6 emissions have been reduced by 97% from 1990 to 2022, 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 2021 to 2022 the emissons increased by 0.5%. The 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 13.7 million tonnes CO_2 equivalents in 2022. This constitutes approximately 28% of the total emissions from all other sectors than LULUCF in the Norwegian GHG accounting.

Forest land is the land-use category responsible for the largest annual variations in CO_2 removals. The increase in carbon stocks is the result of an active forest management policy implemented in the decades after the Second World War, which led to an increase in the area of productive forest and higher productivity in already existing forests. Annual harvesting lower than annual increment also contributed to the increase in carbon stock.

However, a large proportion of these forests are beginning to mature and hence reduce their increment. An increase in natural mortality and harvest intensity over the last decade has also been impacting the carbon stocks, leading to a future decline in living biomass that is already apparent in the data. In addition, deforestation has been higher than afforestation in the last decades.

Croplands followed closely by settlements were the land-use categories that are responsible for the largest net emissions of the six land use categories in the LULUCF sector in 2022.

Table ES- 3: Total emissions of greenhouse gases by sources and removals in Norway 1990-2022. Million tonnes of CO_2 equivalents.

Year	Energy	Industrial processes and product use	Agriculture	LULUCF	Waste	Indirect CO_2 emissions	Total with indirect CO_2 and without LULUCF	Total with indirect CO_2 and with LULUCF	Total without indirect CO_2 and without LULUCF	Total without indirect CO_2 and with LULUCF
1990	28.3	14.8	5.0	-11.8	2.7	0.5	51.3	39.5	50.8	39.0
1995	31.4	12.0	4.9	-14.5	2.6	0.8	51.7	37.1	50.9	36.4
2000	34.2	12.9	4.7	-17.0	2.3	0.9	55.0	38.0	54.1	37.1
2005	36.3	11.3	4.7	-24.8	2.0	0.4	54.8	30.0	54.4	29.6
2010	39.2	8.9	4.5	-26.3	2.0	0.2	54.7	28.4	54.6	28.3
2011	38.0	9.0	4.5	-25.6	2.1	0.2	53.8	28.2	53.6	28.1
2012	37.6	8.9	4.5	-24.6	2.0	0.1	53.2	28.5	53.0	28.4
2013	37.7	9.0	4.5	-21.2	2.0	0.2	53.4	32.2	53.2	32.0
2014	37.9	9.1	4.6	-18.9	1.9	0.2	53.8	34.9	53.6	34.8
2015	38.4	9.2	4.7	-15.1	1.9	0.2	54.3	39.3	54.1	39.1

2016	37.7	9.1	4.7	-13.7	1.8	0.2	53.5	39.8	53.3	39.6
2017	37.1	9.1	4.7	-16.0	1.7	0.2	0.0	0.0	0.0	0.0
2018	37.2	9.1	4.7	-13.0	1.7	0.2	52.8	39.8	52.7	39.7
2019	35.6	9.1	4.7	-8.8	1.6	0.2	51.1	42.3	50.9	42.2
2020	33.8	9.1	4.7	-16.1	1.6	0.2	49.4	33.3	49.3	33.1
2021	33.6	9.3	4.8	-11.7	1.5	0.1	49.3	37.5	49.1	37.4
2022	33.4	9.3	4.6	-13.7	1.4	0.1	48.9	35.1	48.8	35.0

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

ES4 Other information

Nitrogen oxides (NO_x), 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_2) 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_x emissions have decreased by approximately 32% from 1990 to 2022, primarily because of stricter emission regulations directed towards road traffic, which counteracted increased emissions from oil and gas production and from navigation. From 2021 to 2022, the total NO_x emissions decreased by 5.2%.

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 66% from 2001 to 2022 and were, in 2022, 55% lower than in 1990. From 2021 to 2022, NMVOC emissions decreased by 5.9%.

Over the period 1990-2022, emissions of CO decreased by 47%. This is primarily explained by the implementation of new emissions standards for motor vehicles.

Emissions of SO_2 were reduced by 71% from 1990 to 2022. 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.

ES.5 Key category analysis

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. The methods and results from the key category analysis are described in chapter 1 as well as in annex 1.

ES.6. Improvements introduced

The Norwegian Environment Agency co-ordinates the development and improvements of the inventory's different sectors. The recommendations from the UNFCCC 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. The overall aim of inventory improvement is to improve the completeness and transparency and reduce uncertainties associated with the national inventory estimates. The issues are prioritized based on the recommendations from the review team and available human and financial resources. The national greenhouse gas inventory has undergone substantial improvements over the years, and the inventory is largely complete and transparent.

The improvements introduced since the latest UNFCCC review report are listed in chapter 10.

1. National circumstances, institutional arrangements, and cross-cutting information

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_2, CH_4, N_2O as well as fluorinated greenhouse gases (HFCs, PFCs, NF_3 and SF_6), 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 2024 together with the associated Common Reporting Format (CRF) tables are Norway's contribution to the 2024 round of reporting and it covers emissions and removals for the period 1990-2022. Both the National Inventory Report and the CRF tables may be found on the UNFCCC web pages.

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* supplemented by aspects of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 IPCC Refinement), and the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2013 Wetlands Supplement). 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_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)

Norway has examined whether there are activities that would result in emissions of trinitrogenfluoride (NF_3), and our assessment is that there are no emissions of NF_3 in Norway.

When emissions and removals of greenhouse gases are expressed as CO_2 equivalents, Global Warming Potentials over a 100-year time horizon from the IPCC's Fifth Assessment Report have been used.

Indirect CO_2 emissions originating from the fossil part of CH_4 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_x, NMVOC, CO and SO_2, which should be included according to the reporting guidelines. Detailed descriptions of the calculation methodologies for these gases are available in Norway's annual report under 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 circumstances and institutional arrangements

Decision 24/CP.19 requires Annex I parties under the Convention to implement and maintain national inventory arrangements.

1.2.1 National entity or national focal point

The Norwegian Environment Agency has been appointed by the Ministry of Climate and Environment as the national entity through the budget proposition to the Norwegian parliament (Stortinget) for 2015, which states that "*The Norwegian system will build on existing organization and cooperation between the Norwegian Environment Agency, Statistics Norway and the Norwegian Institute of Bioeconomy Research. These three institutions are held individually responsible that their own contributions to the national system are in line with the guidelines from the climate convention on the calculation and archiving of emissions and removals of greenhouse gases. The Norwegian Environment Agency is still appointed as a national entity with overall responsibility for the inventory and reporting*". (St. prop. Nr. 1 (2014-

2015)). This point of the proposition was accepted by the Norwegian parliament without any remarks. The Norwegian Environment Agency as the national entity is responsible for:

- Reporting the greenhouse gas inventory to the UNFCCC, including the National Inventory Report and CRF tables
- Completing the National Inventory Report
- Implementation of a QA/QC plan
- Preparing for UNFCCC inventory reviews and coordinating the communication with the expert review team, including responses to review findings
- Coordinating the cooperative work between the institutions of the national system, including the establishment of formal agreements
- Informing the cooperating institutions about relevant decisions and meetings
- Informing national institutions (e.g., ministries and data providers) about the requirements of the national system and ensuring that existing information in national institutions is considered and used in the inventory where appropriate
- Working to secure adequate funding for all parts of the national system in collaboration with the Ministry of Climate and Environment, The Ministry of Agriculture and Food, and the Ministry of Finance.

1.2.2 Inventory preparation process

The Norwegian GHG 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.

Today, Norway has an integrated inventory system for producing inventories of the greenhouse gases and the air pollutants SO_2, NO_x, 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 largely common for all pollutants.

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. Statistics Norway is responsible for the official statistics on emissions to air, excluding LULUCF. 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 reporting to the UNFCCC is based on the official statistics on emissions to air and the calculations of emissions and removals from LULUCF.

The Norwegian Environment Agency is a government institution. The Norwegian Environment Agency's responsibility for the national system is described in the annual letter from the Ministry of Climate and Environment where the Ministry gives directions on the Norwegian Environment Agency's key priorities and financial resources for the following year. The Section for Emission Inventories and Method holds the main responsibility and coordinating role in the Agency.

Statistics Norway is an independent government institution. Statistics Norway is responsible for the official statistics on emissions to air. Statistics Norway is also responsible for compiling the Norwegian greenhouse gas emission inventory, excluding LULUCF, based on the official statistics on emissions to air. The expenses for production and development of the official statistics on emissions to air and the emission inventory are partly covered by Statistics Norway through its financing from the government budget, and partly through specific project funding from the Norwegian Environment Agency.

The Norwegian Institute of Bioeconomy Research is owned by the Ministry of Agriculture and Food as an administrative agency with special authorization and its own supervisory board. Several units within the institution are involved in the development and production cycle of the LULUCF inventory. The responsibility for coordination, QA/QC and reporting is placed within one of these units, Department of Forest and Climate. The expenses for production and development of the greenhouse gas inventory are partly covered by the Norwegian Institute of Bioeconomy Research through funding from the Ministry of Agriculture and Food and partly through specific project funding from the Norwegian Environment Agency.

A formalized agreement has been signed between the Norwegian Environment Agency as the national entity and the two other institutions. This ensures the continuation of the institutional arrangements for greenhouse gas inventories and reporting for the period from 2023 – 2032. Through these agreements, each institution is obliged to implement internal procedures to fulfill the requirements of the national system, including 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]. Each institution is also obliged to develop the competence of their staff as required. The obligations of the Norwegian Institute of Bioeconomy Research are also guided by an annual allotment letter from the Ministry of Agriculture and Food.

The Norwegian Environment Agency as a national entity is responsible for preparing, organizing, and reporting meetings between the three institutions. The purpose of the cooperation meetings is to discuss and agree on methodological issues, prioritize resources (e.g., considering the review reports) and generally facilitate the implementation

[1] The agreement between the Norwegian Environment Agency and Statistics Norway also includes commitments for data deliveries for reporting under the Convention on Long-range Transboundary Air Pollution (LRTAP).

of the national system. Normally, two cooperation meetings between all three institutions are held every year. The cooperation meeting makes decisions collectively. In addition, bilateral cooperation meetings are arranged between the national entity and each of the other institutions in the national system.

The three institutions of the national greenhouse gas inventory system work together to fulfill the requirements for GHG inventory and reporting.

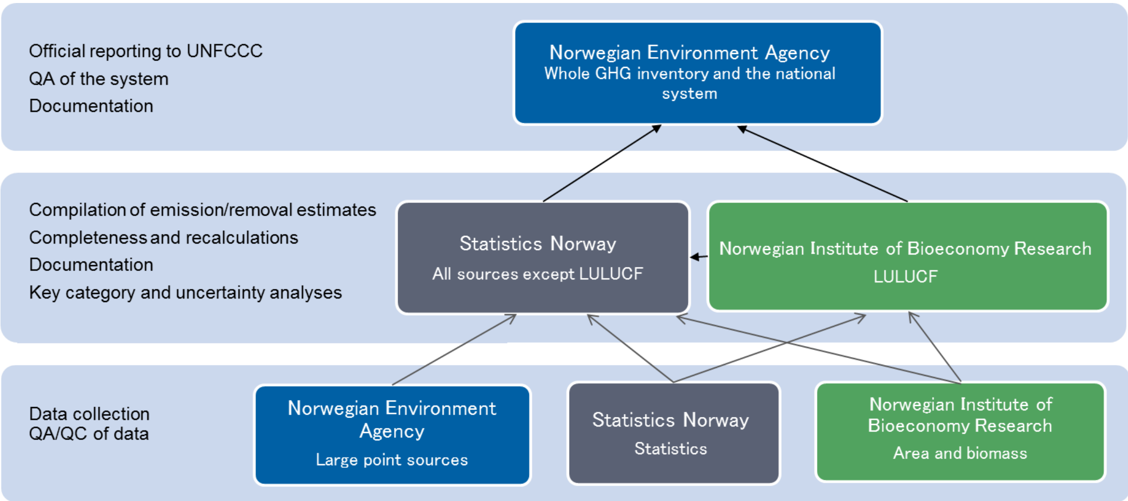

Figure 1.1: Overview of participating institutions, institutional responsibilities, and cooperation.

The three institutions meet regularly to discuss and share experiences with respect to key topics like QA/QC, uncertainty assessment and archiving. These meetings are used to increase the capacity of the project groups in the three institutions. The institutions of the national system may also need to seek partners from other technical authorities or expert institutions to participate in a Tier 2 QA/QC and to improve methodologies and data quality, for example with respect to industrial processes technology, agriculture, soil processes and waste.

The institutions have agreed on a “milestone” production plan (Figure 1.2 and Table 1-1). This production plan reflects national publishing obligations etc. and is supplemented by internal production plans in each of the three institutions.

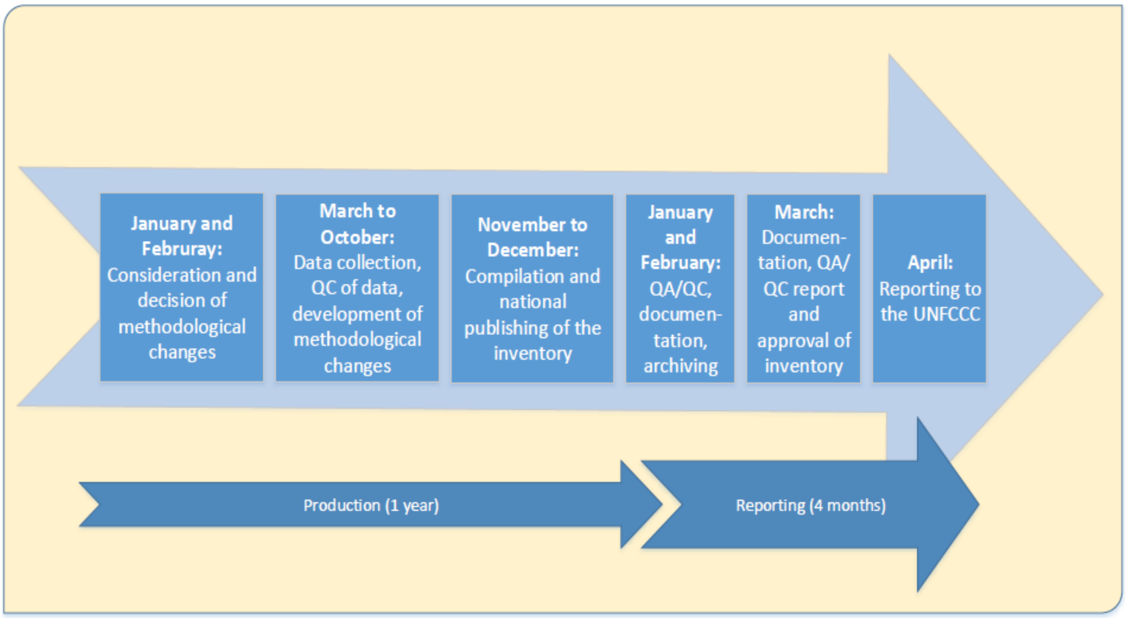

Figure 1.2: The inventory preparation cycle.

Table 1-1: Milestone inventory production plan (indicative dates).

Milestone	Responsible	Deadline
Consideration of methodological changes needed for the next year's reporting, including those based on the review report from last year's reporting cycle	Norwegian Environment Agency	February 1st
Agreement on major methodological changes needed for next year's reporting	All	May 15th
Emission data from large industrial plants sent to Statistics Norway	Norwegian Environment Agency	September 15th
All non-LULUCF data collection completed	Statistics Norway	November 1st
LULUCF area data collection for the previous calendar year completed	Norwegian Institute of Bioeconomy Research	December 1st
National publishing of official statistics on emissions to air1	Statistics Norway	November
QA/QC of the emission estimates from the official statistics to air for use in the emission inventory	Norwegian Environment Agency	January 15th
All data entered into the CRF software	Statistics Norway and Norwegian Institute of Bioeconomy Research	February 1st

Review of documentation and necessary updates made2	All	March 15th
QA/QC of emission inventory in the CRF software completed	All	March 15th
NIR first draft	All	March 15th
QA/QC reports sent to the Norwegian Environment Agency	All	March 30th
NIR finalized	Norwegian Environment Agency	April 13th
QA/QC report finalized	Norwegian Environment Agency	April 13th
Formal approval of the inventory for the purpose of reporting	Norwegian Environment Agency	April 13th
Reporting	Norwegian Environment Agency	April 15th

[1] *The official statistics on emissions to air have a different aggregation of emissions than the greenhouse gas emission inventory reported to the UNFCCC. However, the activity data, emission factors and calculation methodologies are the same.*
[2] *This point includes internal documentation in all institutions as well as external documentation in the Norwegian Institute of Bioeconomy Research and Statistics Norway*

In the agreements, the three institutions that prepare the inventory have defined areas of responsibility for data collection. An overview of institutional responsibilities and cooperation is shown in Figure 1.1.

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 current division of responsibility for the most important data is shown in Table 1-2. The table focuses on data that are updated regularly and not emission factors that are assumed constant over several years. Emission factors are normally collected through dedicated projects. The institutions may agree to reallocate responsibilities through cooperation meetings.

Table 1-2: Main responsibilities for data collection.

Institution	Data type	Data provider
Norwegian Environment Agency	Emissions and activity data from industrial plants (point sources) (around 70 at present, but some of these do not report GHG emissions)	Norwegian Environment Agency
	Emissions from offshore activities, including drilling activities, fugitive emissions, well-testing oil burning and emission factors for crude oil loading	The Norwegian Offshore Directorate and the Norwegian Environment Agency
	Methane recovery from landfills	Norwegian Environment Agency
	Amounts of waste incinerated	Norwegian Environment Agency
	Data on Industrial wastewater	Norwegian Environment Agency
	Import of HFCs, PFCs and SF_6 by application. Import HFCs, PFCs and SF_6 in products	Norwegian Environment Agency and Statistics Norway
		The Norwegian Tax Administration
Statistics Norway	Energy balance/account (energy use by sector and application), energy use in point sources. These statistics are building on several primary data sources (surveys, registers, and censuses)	Statistics Norway
	Production data, import and export	Statistics Norway
	Vehicle registrations	Statistics Norway
	Transport statistics	Statistics Norway, Institute for Transport Economics (TØI), Norwegian Road Federation
	Agriculture statistics, including cultivated area, animal population and manure management	Statistics Norway, Cow Recording System at TINE BA, Norwegian Institute of Bioeconomy Research
	Fertilizer use and lime application	Norwegian Food Safety Authority (Mattilsynet)

		Norwegian Environment Agency
	Waste disposal and waste characteristics	Statistics Norway
	Wastewater statistics	Statistics Norway
	Biological treatment of waste	Statistics Norway
The Norwegian Institute of Bioeconomy Research	Area statistics from the national forest inventory and national land resource surveys	Norwegian Institute of Bioeconomy Research
	Data needed to estimate changes in biomass stocks from the national forest inventory	Norwegian Institute of Bioeconomy Research
	Area and other activity data/statistics from administrative sources, i.e., agriculture statistics	Statistics Norway
	Climate and meteorological data needed to calculate soil carbon	SeNorge; Norwegian Meteorological Institute, The Norwegian Water Resources and Energy Directorate (NVE)
	Activity data for HWP	FAO
	Fertilizer use on forest land	Statistics Norway
	Extracted peat volume	Norwegian Food Safety Authority and the Norwegian Institute of Bioeconomy Research
	Forest fires	Directorate for Civil Protection and Emergency Planning

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 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.

The data collection and data management are secured on a legal basis through three main acts, the Pollution Control Act, the Greenhouse Gas Emission Trading Act and the Statistics Act.

The *Pollution Control Act*[2] gives the Norwegian Environment Agency the authority to collect and review emission data from large industrial plants. Emissions of greenhouse gases are part of the Pollution Control Act. The Pollution Control Act is a typical enabling act. This means that the details in each case are outlined in discharge permits and regulations issued by the pollution control authorities. The Act was established for the purpose of preventing and reducing harm and nuisance from pollution. This is reflected in the main rule of the act, which says that pollution is forbidden, unless it is specifically permitted by law, regulations, or individual permits.

Collection and checking of GHG emission data are also covered by the *Greenhouse Gas Emission Trading Act*[3]. The implementation rules are stipulated in a regulation[4].

Statistics Norway is a professional independent institution, which through The Statistics Act[5] has been given "the right to impose upon any person an obligation to provide information necessary for the production of official statistics in so far as any legally prescribed obligation of secrecy is no obstacle thereto". The Statistics Act gives Statistics Norway access to public administrative data-processing systems and to choose the statistical methods which form the basis for the preparation of official statistics. Statistics Norway is responsible for how and when official statistics are published. The Ministry of Finance is administratively responsible for Statistics Norway, and the fiscal budget for its business is set by the Government and the Norwegian parliament.

The collected data are subjected to the Quality Assessment and Quality Control (QA/QC) routines described in section 1.5 and Annex 5, as well as source specific routines as described under each source chapter. They are all (except data regarding LULUCF) sub-sequently 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.

1.2.3 Archiving of information

The reporting guidelines in decision 24/CP.19 identify what a Party should archive:

- Disaggregated emission factors and activity data
- Documentation of data collection, assumption, and aggregation
- Internal documentation on QA/QC procedures
- External and internal reviews
- Documentation on annual key sources
- Planned inventory improvements.

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[2] https://www.regjeringen.no/en/dokumenter/pollution-control-act/id171893/

[3] https://www.regjeringen.no/en/dokumenter/greenhouse-gas-emission-trading-act/id172242/

[4] https://lovdata.no/dokument/SF/forskrift/2004-12-23-1851?q=klimakvote

[5] https://lovdata.no/dokument/NL/lov/1989-06-16-54?q=statistikkloven

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.

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, see Table 1-3 for an overview.

The common rules for archiving of data are the following:

- Data and information are archived for each submission year.
- Data and information are archived in a single location within each institution (this may imply double archiving).
- Archiving for a submission year includes:
  - All input data
  - All estimated emissions
  - All partly filled-in or final CRF
  - All technical documentation
  - Recalculations of previous estimates if any
  - The NIR (where relevant)
- The file structure is documented.
- The platform at which the data and information is archived undergoes a daily backup and the backup is securely saved.

Table 1-3: Responsibilities for archiving information. Capital, bold X indicates archiving also of datasets sent from the other institutions.

	Norwegian Environment Agency	Statistics Norway	Norwegian Institute of Bioeconomy Research	Comments
Disaggregated emission factors	x	**X**	x	All EF except LULUCF are archived by Statistics Norway
Activity data	x	**X**	x	
Emission data collected from large plants	**X**	**X**		Statistics Norway does not collect these data,

				but archived as part of the emission model
Documentation of data collection, assumption, and aggregation	**X**	**X**	x	Norwegian Environment Agency is developing a library of all important reports (including background reports)
Internal documentation on QA/QC procedures	x	x	x	
External and internal reviews	**X**	x	x	
Documentation on annual key categories		x		
Planned inventory improvements	**X**			
Estimated emissions (model output)		**X**	x	
CRF	**X**	(x)		
NIR	**X**			
Recalculations	**X**	**X**	x	

By systematic archiving as described above, all information can be made available to a review team. However, data archived at Statistics Norway are subject to rules of confidentiality, and this must be taken into consideration during reviews. Confidential information from Statistics Norway can be made available to the review team when the revision takes place in Statistics Norway's premises and after a confidentiality declaration is signed. The most relevant documentation is available in the central archive of the Norwegian Environment Agency. Comprehensive documentations for LULUCF and other emission sources are available in English. Additional technical documentation may be in Norwegian only, as will the emission reports from the plants.

The Norwegian Environment Agency, Statistics Norway and The Institute of Bioeconomy Research are responsible for having competent personnel on duty during a review to access data if requested.

1.2.3.1 Statistics Norway

Archiving of the emission inventory in Statistics Norway takes place at several levels:

1) The inventory is a part of Statistics Norway's central data archiving system. All input data to and results from the general emission model from every publication cycle

are stored and documented in this system. Archiving is made after each inventory calculation has been finalized.

2) Input data received as spreadsheets, mail, etc, are stored in folders for every publication cycle. These folders also include preliminary calculations before data are entered into the general emission model.
3) Several input data are used in preliminary calculations before entering the general Norwegian emission inventory model. This includes satellite models such as road traffic and waste, as well as several simpler calculations that do not fit into the framework of the general model. The preliminary calculations are not included in the central archiving system, which is not suited for such a diverse collection of data. For some satellite models there is an established archiving routine where all input data and results from every calculation cycle are stored.
4) During improvement projects, adaptation of activity data or calculations of emission factors are often performed. Examples are emission factors for flaring and air traffic. These improvement projects are not archived as part of the annual folder system but are stored in separate folders. They are not overwritten when new methodologies, emission factors or activity data are implemented.

Statistics Norway will improve its archiving system in line with the requirements for the national system. This will include improved archiving of input and output from side models (satellite models). These will be archived in one place and the storage of revised versions due to recalculations will be improved as will the documentation of recalculations. Recalculations are documented for internal use. This document will receive increased status and its accessibility will be improved.

1.2.3.2 The Norwegian Environment Agency

From 2009 the Norway's official report is uploaded to UNFCCC submission portal. The CRF tables and NIR are also uploaded to REPORTNET from 2002 and will also be uploaded there in the future. Before 2002 the reports are stored at the Norwegian Environment Agency's server.

Reports with emission data and QA control from large industrial plants are sent to the Norwegian Environment Agency and archived in Elements. Elements is an electronic recordkeeping tool that meets the specifications set by the Noark Standard. The Noark Standard is a specification of functional requirements for electronic recordkeeping systems used in public administration in Norway and has been approved by the Norwegian National Archives. These data reported from the plants are then stored in the Forurensning database[6]. If a plant submits additional information as a result of the QA/QC, this information will also be archived in Elements and Forurensning will be corrected accordingly. After QA/QC as described in 1.5, the data (with supplementary notes) for the

[6] The Forurensning database replaced the previous database INKOSYS in 2006. All data in INKOSYS is transferred to Forurensning.

large industrial plants are stored and archived in a designated file on the Norwegian Environment Agency's server, before being sent to Statistics Norway.

Emission data from offshore oil and gas production are archived in Footprint. This is a database operated by the Norwegian Offshore Directorate, the Norwegian Environment Agency, and Offshore Norge. The Norwegian Environment Agency aggregates data from Footprint. The data are stored and archived in a designated file on the Norwegian Environment Agency's server before being sent to Statistics Norway.

Emission data from the landfill owners are sent to the County Departments of Environmental Affairs and are then stored in the Forurensning database. After QA/QC, these data (with supplementary notes) are stored and archived in a designated file on the Norwegian Environment Agency's server before being sent to Statistics Norway

Companies that import HFC/PFC and SF_6 in bulk reported this information to the Norwegian Environment Agency annually up to 2009. The reports are archived in Elements. After 2009, Statistics Norway collects the amounts of imported and exported gases from registers at the Norwegian Directorate of Customs and Excise. All import of F-gases is covered in these registers, as Norway lays a tax on the import of F-gases.

1.2.3.3 The Norwegian Institute of Bioeconomy Research

The tables and data programs etc. are currently being stored on the institute's server. Every night a new backup copy is made and stored outside the building. This will ensure that no data can disappear due to technical failure. Files that have been left unchanged will, therefore, exist as long as there is a wish to keep them. Even after purposely deleting or changing the data, the files will exist for 2-3 months, or until the data tapes are overwritten with new data.

1.2.4 Processes for official consideration and approval of inventory

The Norwegian Environment Agency as the national entity approves the inventory before official submission to the UNFCCC. As a basis for approving the inventory, the Norwegian Environment Agency will consider the completion of the inventory and the National Inventory Report. The Norwegian Environment Agency will also review:

- The QA/QC report from the QA/QC responsible in the Norwegian Environment Agency, attaching QA/QC reports from the institutions of the national system.
- Methodological changes and recalculations
- Minutes from the cooperation meetings between the institutions
- Other matters of relevance for the approval of the inventory

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

1.3.1 The main emission model

The main emission 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.

The model is programmed in SAS system software and is flexible with respect to output, i.e., it can produce tables (input and output) in accordance with different aggregation levels and parameters. Furthermore, it has been designed to fit the availability and aggregation of input data and is flexible with respect to changes. Emission factors can be entered for groups of years.

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:

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

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. After energy use has been allocated in this way, the energy accounts may be viewed as a cube in which the three axes are fuels, industries, and sources.

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. Thus, the factors may be viewed as a four-dimensional “cube” with pollutants as the additional dimension. 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. There are more than 30 fuels and about 30 technical sources used for energy combustion.

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 for non-combustion emissions and for combustion without energy use 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. Information about the geographical distribution of emissions is useful for modelling and control purposes and constitutes a fifth axis.

1.3.2 The LULUCF model

The Norwegian Institute of Bioeconomy Research is in charge of estimating emissions and removals from Land use, Land-Use Change and Forestry (LULUCF) for all categories where area statistics and living biomass are used for activity data. A software-based calculation system that primarily uses the statistical software R (R Core Team, 2020), in an environment with version control (Gitlab), and microsoft excel has been developed for the implementation of the IPCC good practice guidance for the LULUCF sector. The systems use 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 harvested/dead and living tree biomass and field observations necessary to apply a range of estimation methods based on the IPCC GPG. 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 data from the NFI is complemented with many other datasets in order to produce emission/removal estimates for all relevant land use categories (Table 1-2). Details on all methods and datasets in use are provided in the annual NIR and references therein.

The sampling design of the NFI is based on a systematic grid of geo-referenced sample plots covering the entire country. The NFI is a continuous forest inventory in which 1/5th of the sample plots are revisited each year. This results in 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. To confirm the land use and the extent of the area of forest and other wooded land at higher altitudes and in Finnmark County, the NFI conducted a complete forest inventory during 2005–2010 for these areas. 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 land use, land-use change, and carbon stock change above the coniferous limit and in Finnmark County, have been back-casted to close the gap from the start of the National Forest Inventory (1986-1993) to the beginning of the supplementary inventories (Finnmark, forest above the coniferous limit) (see detail in the annual NIR).

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.

1.3.3 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_2O from agriculture, CH_4 and N_2O 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).

Table 1-4: Data providers and sources for the emission inventory.

	Very important	Important	Less important
1. Data from Statistics Norway			
Energy statistics	X		
Consumer surveys			X
Living condition survey			X
Foreign trade statistics		X	
Production statistics			X
Petroleum statistics	X		
Agriculture statistics	X		
Waste statistics		X	
Wastewater statistics			X
Vehicle registry		X	

Transport statistics		X	
2. Other institutions			
The Norwegian Institute of Bioeconomy Research	X		
Norwegian Environment Agency	X		
Forurensning (pollution)	X		
Footprint (previously EEH and Environmental Web (including data from the Norwegian Offshore Directorate))	X		
FAOSTAT (Food and Agriculture Organization of the United Nations, Statistics division)	X		
Norwegian Meteorological Institute	X		
Norwegian Petroleum Industry Association			X
Norwegian Offshore Directorate		X	
Institute of Transport Economics			X
Norwegian Road Federation (Opplysningsrådet for veitrafikk)		X	
Norwegian Food Safety Authority			X
The Directorate for Civil Protection		X	
Directorate of Customs and Excise		X	
Stiftelsen Returgass			X

1.3.4 Recalculations

In accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 1, chapter 5 (IPCC 2006) Norway routinely evaluates whether recalculations of historical data are needed. Recalculations are made if there have been methodological changes influencing emissions in previous years or changes in data due to correction of errors or changes in preferred data sources.

When data sources are not available for the whole time series since 1990, one of the proposed methods from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 1, chapter 5 (IPCC 2006) is used to splice data (or more sophisticated methods if relevant). Normally extrapolations using drivers correlated with emissions or the overlap method is used. Smaller emission sources may be linearly extrapolated (or kept constant). The method is chosen based on available data and suitability of drivers.

Data from the National Forest Inventory are collected over a period of five years. Each year provides a statistically representative coverage of Norwegian forests, but with only 1/5 of the statistical support of the full inventory. Annual reports can be issued based on the annual data but are known to result in large inter-annual variations. Plotwise interpolation is used to gap-fill the area for the missing years between two observations. And plot wise extrapolation of the area based on the trend for the last 10 years, is used to gap-fill the last years of the timeseries (only required for 4/5ths of the plots). All carbon stock change (CSC) estimates based on area estimates use the full plot wise interpolated-extrapolated area dataset to provide yearly CSC estimates for each plot.

1.4 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 key category assessment is made by Statistics Norway using the IPCC Tier 1 and the Tier 2 method, which includes uncertainty estimates. The assessment is updated annually and is made for the level and trend since 1990. Statistics Norway also considers the qualitative criteria for identification of key categories. In accordance with the IPCC good practice guidance for LULUCF (IPCC 2006) the analysis is made in two parts, one excluding LULUCF emissions and removals and another integrating LULUCF with the rest of the inventory. Due to the large LULUCF sink in Norway, the results of these two parts are quite different.

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 1-5 (excluding LULUCF). In addition, we have also included a category identified on qualitative criteria. Altogether there are 47 key categories. Key categories in LULUCF were identified in separate analyses and are summarized in Table 1-6.

The complete analyses are included in Annex 1 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.
The trend assessment approach 1 is performed according to the 2019 refinements, equation 4.2.

Table 1-5: Summary of identified emission key categories. Excluding LULUCF.

IPCC Category code	IPCC Category	Grenhouse Gas	Identification criteria[1]				Method
1A1,1A2,1A4	Fuel Combustion Activities (Sectoral Approach) Biomass	CH_4	L1		L2	T2	Tier 2
1A1,1A2,1A4	Fuel Combustion Activities (Sectoral Approach) Gaseous Fuels	CO_2	L1	T1	L2	T2	Tier 2
1A1,1A2,1A4	Fuel Combustion Activities (Sectoral Approach) Liquid Fuels	CO_2	L1	T1	L2	T2	Tier 2
1A1,1A2,1A4	Fuel Combustion Activities (Sectoral Approach) Other Fuels	CO_2	L1	T1	L2	T2	Tier 2
1A3B	Road Transportation	N_2O			L2		Tier 2
1A3D	Navigation	CO_2	L1	T1	L2	T2	Tier 2
1A3D	Navigation	CH_4			L2	T2	Tier 2
1A4	Other sectors	CO_2	L1	T1	L2	T2	Tier 2
1A5B	Mobile	CO_2	L1	T1		T2	Tier 2
1B1A	Coal Mining	CH_4			L2	T2	Tier 1
1B2A	Oil (incl. oil refineries, gasoline distribution)	CO_2	L1	T1	L2	T2	Tier 2
1B2A	Oil (incl. oil refineries, gasoline distribution)	CH_4			L2	T2	Tier 2
1B2C	Venting and Flaring	CO_2	L1	T1	L2	T2	Tier 3
1B2C	Venting and Flaring	CH_4			L2	T2	Tier 3
2A1	Cement Production	CO_2	L1				Tier 3
2A2	Lime Production	CO_2		T1			Tier 3
2B1	Ammonia Production	CO_2	L1		L2		Tier 2

2B2	Nitric Acid Production	N_2O	L1	T1	L2	T2	Tier 3
2B5	Carbide Production	CO_2		T1		T2	Tier 2
2B8	Petrochemical and carbon black production	CO_2	L1		L2		Tier 2
2C2	Ferroalloys production	CO_2	L1	T1	L2		Tier 2/3
2C3	Aluminium production	CO_2	L1	T1	L2	T2	Tier 2/3
2C3	Aluminium production	PFC	L1	T1	L2	T2	Tier 2
2C4	Magnesium production	SF_6	L1				Tier 2
2F	Product uses as substitutes for ODS	HFC	L1	T1	L2	T2	Tier 2
3A1	Cattle	CH_4	L1		L2	T2	Tier 2
3A2	Sheep	CH_4	L1		L2		Tier 2
3A4	Other	CH_4			L2		Tier 1
3B1	Manure Management - Cattle	CH_4			L2		Tier 2
3B5	Manure Management	N_2O			L2		Tier 2
3D11	Synthetic Fertilizers	N_2O	L1		L2		Tier 1
3D12	Organic N fertilizer	N_2O			L2		Tier 1
3D14	Crop Residue	N_2O			L2		Tier 1
3D16	Cultivation of Histosols	N_2O			L2		Tier 1
3D22	Nitrogen Leaching and Run-off	N_2O			L2		Tier 1
5A1A	Managed Waste Disposal sites. Anaerobic	CH_4	L1	T1	L2	T2	Tier 2
5B	Biological treatment of Solid Waste	CH_4				T2	Tier 1
5D1	Domestic Wastewater	CH_4			L2		Tier 1

[1] *"L" refers to level and "T" to trend analyses. Numbers refer to approaches. "Q" refers to qualitative criteria.*

[2] *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 2022 did not identify any new sources.

The Approach 1 trend analysis (excluding LULUCF) did not identify any new sources.

The Approach 2 level analysis identified one new source: N_2O from Road transportation.

The Approach 2 trend analyses identified two new sources: CO_2 from Civil Aviation and CH_4 from Road transportation.

Three sources are no longer key categories: CH_4 from Fuel Combustion Activities (Sectoral Approach) Gaseous Fuels and Natural gas, and N_2O from Indirect emissions from managed soils – Atmospheric deposition did not qualify in neither of the level- and trend approaches.

Table 1-6: Summary of identified LULUCF key categories.

IPCC Category code	IPCC Category	Grenhouse Gas	Identification criteria[1]				Method
4(II)Crop	Cropland - drained organic soil - Organic soil CC + LC	CH_4			L2		Tier 1
4(II)Forest	Forest land - drained organic soils - Drained organic soil	N_2O			L2		Tier 1
4.A.1.i	Forest remaining forest - Litter + dead wood + Mineral soil	CO_2	L1	T1	L2	T2	Tier 3
4.A.1.i	Forest remaining forest - Living biomass	CO_2	L1	T1	L2	T2	Tier 3
4.A.1.i	Forest remaining forest, drained organic soils - Organic soil	CO_2	L1		L2		Tier 1
4.A.2.1	Cropland to Forest - Dead wood	CO_2			L2		Tier 1
4.A.2.1	Cropland to Forest - Litter	CO_2			L2		Tier 1
4.A.2.2.ex	Extensive Grassland to Forest - Dead wood	CO_2		T1	L2	T2	Tier 1
4.A.2.2.ex	Extensive Grassland to Forest - Litter	CO_2		T1	L2	T2	Tier 1
4.A.2.2.in	Intensive Grassland to Forest - Dead wood	CO_2			L2	T2	Tier 1
4.A.2.2.in	Intensive Grassland to Forest - Living biomass	CO_2			L2	T2	Tier 1/3
4.A.2.2.in	Intensive Grassland to Forest - Litter	CO_2			L2	T2	Tier 1
4.A.2.3.i Un	Unmanaged Wetland to Forest - Dead wood	CO_2			L2	T2	Tier 1
4.A.2.3.i Un	Unmanaged Wetland to Forest - Living biomass	CO_2				T2	Tier 3

4.A.2.3.i Un	Unmanaged Wetland to Forest - Litter	CO_2			L2	T2	Tier 1
4.A.2.4	Settlement to Forest - Dead wood	CO_2			L2	T2	Tier 1
4.A.2.4	Settlement to Forest - Living biomass	CO_2			L2	T2	Tier 1/3
4.A.2.4	Settlement to Forest - Litter	CO_2			L2	T2	Tier 1
4.B.1.i	Cropland remaining cropland - Organic soil	CO_2	L1	T1	L2	T2	Tier 1
4.B.2.1	Forest to Cropland - DOM	CO_2	L1	T1	L2	T2	Tier 1
4.B.2.1	Forest to Cropland - Living biomass	CO_2			L2	T2	Tier 1/3
4.B.2.1	Forest to Cropland - Mineral soil	CO_2			L2		Tier 1
4.B.2.1	Forest to Cropland - Organic soil	CO_2			L2		Tier 1
4.B.2.3	Unmanaged Wetland to Cropland - Organic soil	CO_2			L2	T2	Tier 1
4.C.1.i ex	Extensive Grassland remaining extensive grassland - Living biomass	CO_2	L1	T1	L2	T2	Tier 3
4.C.1.i in	Intensive Grassland remaining intensive grassland - Living biomass	CO_2			L2		Tier 2/3
4.C.1.i in	Intensive Grassland remaining intensive grassland - Mineral soil	CO_2				T2	Tier 1
4.C.1.i in	Intensive Grassland remaining intensive grassland - Organic soil	CO_2			L2		Tier 1
4.C.2.1.i.in	Forest to Intensive Grassland - DOM	CO_2	L1	T1	L2	T2	Tier 1
4.C.2.1.i.in	Forest to Intensive Grassland - Living biomass	CO_2				T2	Tier 1/3
4.D.1.1	Wetland Peat extraction - on+off-site - Organic soil	CO_2			L2		Tier 2
4.D.1.3.i M	Managed Wetlands remaining managed wetlands - Organic soil	CO_2			L2		Tier 1
4.D.2.3.1	Forest to Managed Wetland - DOM	CO_2			L2		Tier 1
4.E.1.1	Settlements remaining settlements - Organic soil	CO_2			L2	T2	Tier 1
4.E.2.1.1	Forest to Settlement - DOM	CO_2	L1		L2	T2	Tier 1
4.E.2.1.1	Forest to Settlement - Living biomass	CO_2	L1		L2		Tier 1/3
4.E.2.1.1	Forest to Settlement - Mineral soil	CO_2			L2	T2	Tier 1

4.E.2.1.1	Forest to Settlement - Organic soil	CO_2			L2		Tier 1
4.E.2.2.1	Cropland to Settlement - Mineral soil	CO_2			L2	T2	Tier 1
4.E.2.4.1	Unmanaged Wetland to Settlement - Organic soil	CO_2				T2	Tier 1
4.G	Harvested wood Products - HWP	CO_2	L1	T1	L2	T2	Tier 1

1 "L" refers to level and "T" to trend analyses. Numbers refer to approaches.

1.5 Brief general description of QA/QC plan and implementation

Good practice defines the data quality objectives to be *transparency, completeness, consistency, comparability, and accuracy*. These objectives are used as a foundation of the QA/QC system implemented in Norway. In addition, we consider *timeliness* as part of the data quality objectives.

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-procedures have been developed continuously since then.

Norway has implemented a formal quality assurance/quality control plan. 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.

The institutions of the national system have implemented the QA/QC plans by establishing internal procedures. These procedures assign internal responsibilities for the QA/QC checks and facilitate input to the QA/QC report. The QA/QC procedures are under continuous development, and inventory compilers in all institutions of the national system are informed about the data quality objectives of the national system, as well as any priority areas related to the development of the QA/QC procedures.

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.

See Annex 4 for more details on the QA/QC plan and QA/QC procedures.

1.6 General uncertainty assessment, including data pertaining to the overall uncertainty of inventory totals

Norway has quantified uncertainties in input data (activity data and emission factors) and in total emissions and its trend. The uncertainties in input data have been made in consultation with sector experts, combining expert judgments by source experts, information in the IPCC 2006 Guidelines (IPCC 2006) with other sources of information. The uncertainties are combined using the IPCC approach 2 method (bootstrap techniques). The uncertainty analysis of the total inventory is performed annually on emission data for 1990 and the last year of the emission inventory. Uncertainty estimates for sources are also updated annually when the estimation methods or data sources are being changed.

Uncertainties in the LULUCF sector are based on the uncertainty of an activity estimate – typically an area estimate - combined with the uncertainty of the emission or removal per unit activity – typically a carbon stock change estimate. Uncertainties in the area estimates are based on sampling methodology. Uncertainties in the carbon stock change estimates are based on a variety of methodologies. Sampling methodology is applied for tree living biomass, which is the largest sink or source category, while other sources are based on default factors, peer-reviewed studies, and expert judgments. In cases where the methodology for calculating the uncertainties is too complex for standard error propagation methods (Approach 1), Monte Carlo simulation (Approach 2) is instead performed.

1.6.1 Approach 1 uncertainty analysis

The uncertainties in the emission levels for 2022 have been investigated by an approach 1 analysis. The results are given in

Table 1-7 and Table 1-8.

Table 1-7: Approach 1 uncertainties in emission levels, excluding LULUCF.

2022	m (mean)	Uncertainty 2s (% of mean)
Total	48.8 mill. tonnes	3
CO_2	40.8 mill. tonnes	3
CH_4	4.9 mill. tonnes	11
N_2O	2.2 mill. tonnes	22
HFC	747 ktonnes	51
PFC	122 ktonnes	20
SF_6	71 ktonnes	44

Table 1-8: Approach 1 uncertainties in emission levels, including LULUCF.

2022	m (mean)	Uncertainty 2s (% of mean)
Total	35.1 mill. tonnes	14
CO_2	26.6 mill. tonnes	18
CH_4	5.1 mill. tonnes	11
N_2O	2.4 mill. tonnes	21
HFC	747 ktonnes	51
PFC	122 ktonnes	20
SF_6	71 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 1-9 to Table 1-12. The approach 2 analysis is also further described in Annex 2.

The uncertainty in the Norwegian emission inventory was initially investigated systematically in three reports (Kvingedal et al. 2000; Rypdal 1999; Rypdal & Flugsrud 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 LULUCF-sector (Land Use, Land-Use Change and Forestry).

Table 6.2 from the IPCC good practice guidance is included in Annex 2. 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_2 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 1-9 and Table 1-10.

Table 1-9: Uncertainties in emission levels. Each gas and total GWP weighted emissions. Excluding the LULUCF sector.

1990	**m (mean)**	**Fraction of total emissions**	**Uncertainty 2s (% of mean)**
Total	51.3 mill. tonnes	1	3
CO_2	35.0 mill. tonnes	0.68	3
CH_4	6.8 mill. tonnes	0.13	15
N_2O	3.8 mill. tonnes	0.07	10
HFC	50 tonnes	0.00	50
PFC	3.5 mill. tonnes	0.07	20
SF_6	2.2 mill. tonnes	0.04	1
2022	**m (mean)**	**Fraction of total emissions**	**Uncertainty 2s (% of mean)**
Total	48.8 mill. tonnes	1	3
CO_2	40.8 mill. tonnes	0.83	3
CH_4	4.9 mill. tonnes	0.10	11
N_2O	2.2 mill. tonnes	0.05	17
HFC	746.8 ktonnes	0.02	51
PFC	122.2 ktonnes	0.00	20
SF_6	70.9 ktonnes	0.00	44

Table 1-10: Uncertainties in emission levels. Each gas and total GWP weighted emissions. Including the LULUCF sector.

1990	m (mean)	Fraction of total emissions	Uncertainty 2s (% of mean)
Total	39.5 mill. tonnes	1	12
CO_2	22.8 mill. tonnes	0.58	19
CH_4	6.9 mill. tonnes	0.18	15
N_2O	4.0 mill. tonnes	0.10	11
HFC	50 tonnes	0.00	51
PFC	3.5 mill. tonnes	0.09	20
SF_6	2.2 mill. tonnes	0.05	2
2022	**m (mean)**	**Fraction of total emissions**	**Uncertainty 2s (% of mean)**
Total	35.1 mill. tonnes	1	14
CO_2	26.6 mill. tonnes	0.76	18
CH_4	5.1 mill. tonnes	0.15	11
N_2O	2.4 mill. tonnes	0.07	17
HFC	746.8 ktonnes	0.02	51
PFC	122.2 ktonnes	0.00	20
SF_6	70.9 ktonnes	0.00	44

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_2 is known with an uncertainty of 3% of the mean. The total uncertainty level was 3% of the mean in 2022.

There have been major changes in uncertainty level for the different emission components between the two years. The highest uncertainty change between 1990 and 2022 is in the uncertainty estimates for the SF_6 emissions, which has increased from 1 to 44% of the mean. However, the SF_6 emissions are strongly reduced because magnesium production was closed. The figures for the emission of SF_6 from magnesium production was quite well known, but now a larger part of the SF_6 emissions comes from sources with higher uncertainty. For N_2O there is also increase in the uncertainty between the years. One reason for the change can be found in that N_2O from the production of synthetic fertilizer with a quite low uncertainty contributes to a smaller part of the total N_2O emissions in 2022 than in 1990.

Introducing updated uncertainty estimates for N_2O emission factors both for inorganic fertilizer and indirect soil emissions (IPCC 2019) contributed to a lower N_2O uncertainty in the 2024 submission compared to previous submissions. For the other gases there are only smaller changes in the uncertainty from 1990 to 2022.

By including the LULUCF sector the results from the analysis show a total uncertainty of 12% of the mean in 1990 and 14% in 2022. 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 1-11 and Table 1-12.

Table 1-11: Uncertainty of emission trends. 1990-2022. Excluding the LULUCF sector.

	% change ((m2022-m1990) * 100/m1990)	Uncertainty (2*s*100/m1990)
Total	-5	3
CO_2	17	3
CH_4	-27	11
N_2O	-42	5
HFC[1]	..	..
PFC	-97	20
SF_6	-97	1

Table 1-12: Uncertainty of emission trends. 1990-2022. Including the LULUCF sector.

	% change ((m2022-m1990)*100/m1990)	Uncertainty (2*s*100/m1990)
Total	-11	6
CO_2	17	9
CH_4	-26	10
N_2O	-39	4
HFC1	..	..
PFC	-97	19
SF_6	-97	1

[1] 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 2022 is 5%, with an uncertainty in the trend of ± 3 percentage points, when the LULUCF sector is not included. This means that the 2022 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 -11%, with a trend uncertainty of ±6 percentage points.

1.7 General assessment of completeness

1.7.1 Information on completeness (including information on non-reported categories or any methodological or data gaps in the inventory)

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.

Except for the LULUCF sector, the inventory includes emissions on the archipelago Svalbard as well as on mainland Norway. In particular, emissions from coal mining on Svalbard are included.

1.7.2 Description of insignificant categories, if applicable

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_2 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 2022 as reported in this NIR as the basis for national total GHG emissions. The national total GHG emissions without LULUCF in 2022 is reported to be 48 879 492 tonnes CO_2 equivalents. The threshold for an individual emission to be considered insignificant is therefore 24 440 tonnes CO_2 equivalents while the total threshold to be considered insignificant is 48 879 tonnes CO_2 equivalents.

The emissions that Norway has considered as insignificant or because they were non-mandatory, and their likely level of emissions are presented in

Table 1-13. The individual emissions excluded are all below the individual threshold and the total emissions excluded are also below the total threshold.

Table 1-13: Emissions considered insignificant and reported as NE.

CRF code	Description of emission source	Gases	Likely level of emissions (tonnes CO_2 equivalents)
1C1a	CO_2 transport and storage; Pipelines	CO_2	Less than 200 tonnes. See chapter 3.5.
3A4, 3B4	Other animals: Enteric fermentation and manure management	CH_4, N_2O	See chapter 5.6.2. Includes ostrich, llama, etc. Emissions from ostrich were reported in previous submissions and were less than 500 t CO_2 eq when population was highest. Other animals have smaller populations.
3D	Agricultural soils	CH_4	No methodology, see note to CRF Table3s2.
4D1	Wetlands – flooded land remaining flooded land	CO_2	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_2	Estimated to less than 10 000 t CO_2 eq and hence considered to be a negligible source. See below details on the methodology used for the estimation.
4(II)	Emissions from drainage and rewetting	CO_2, CH_4 and N_2O	It is not mandatory to estimate emissions from rewetting organic or mineral soils.
4(V)	Biomass burning – controlled burning- forest land	CH_4 and N_2O	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_2 eq. See below details on the methodology used for the estimation.
4(V)	Biomass burning- wildfires – grassland	CH_4 and N_2O	We assume emission from wildfires on grasslands are negligible because these very rarely occur. Emissions are estimated to be in the range of 1 200 - 7 000 t CO_2 eq. See below details on the methodology used for the estimation.
5C1	Cremation	CH_4, N_2O	No methodology. NO_x emissions from cremation is reported in 5C as 10-15 tonnes/year. CH_4 and N_2O emission factors for combustion are generally lower than NO_x factors, so the NO_x emission is likely an upper bound. Biogenic CO_2 is also reported as NE.
5C2	Open burning of waste	CO_2, CH_4, N_2O	Order of 1 200 t CO_2 eq. by estimate from 1999.
	Total		Estimated emissions less than 19 000 t CO_2 eq.

For the emissions from LULUCF sector considered negligible, see below for further details on the assessment of the approximate and likely emissions given limited data sources to see if they qualify as non-significant.

Peat extraction: The likely level of emissions of CO_2 is 9.1 kt yr^{-1} (range 7.4 - 11.3 kt yr^{-1}). For CH_4, the likely emissions are 0.4 kt CO_2 eq yr^{-1}, and for N_2O, it is 0.1 kt CO_2 eq yr^{-1}. For both CH_4 and N_2O, the likely level of emissions makes up less than the threshold calculated at the beginning of this section. We conclude that these emissions qualify as being non-significant.

Controlled fires: The likely level of emissions of CH_4 is 0.032 kt CO_2 eq yr^{-1}, and for N_2O, it is 0.017 kt CO_2 eq yr^{-1}. For both CH_4 and N_2O, the likely level of emissions makes up less than the threshold calculated at the beginning of this section. We conclude that these emissions qualify as being non-significant.

Grassland wildfires: The likely level of emissions of CH_4 is 2.2 kt CO_2 eq yr^{-1}, and for N_2O, it is 1.1 kt CO_2 eq yr^{-1}, expressed as the mean for the years 2016-2019. For individual years, emissions of CH_4 range from 0.8 to 4.6 kt CO_2 eq yr^{-1}; for N_2O, they range from 0.4 to 2.4 kt CO_2 eq yr^{-1}. For both CH_4 and N_2O, the likely level of emissions makes up less than the threshold calculated at the beginning of this section. We conclude that these emissions qualify as being non-significant.

1.7.3 Total aggregate emissions considered insignificant, if applicable

The total aggregate emissions considered insignificant are less than 19 000 t CO_2 eq.

1.8 Metrics

In accordance with decisions 6/CP.27, the emissions and removals are expressed in CO_2 equivalents by using the global warming potential values, excluding the value for fossil methane, over a 100-year time horizon listed in table 8.A.1 of the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

2. Trends in Greenhouse Gas Emissions and removals

2.1 Description of emission and removal trends for aggregated GHG emissions and removals

In 2022, total greenhouse gas (GHG) emissions in Norway were 48.9 million tonnes of carbon dioxide equivalents, which is a decrease of 0.4 million tonnes compared to 2021. Emissions reached their peak at 56.4 million tonnes in 2007. They have since decreased by 13%, and were in 2022 2.4 million tonnes, or 4.6%, lower than in 1990. The net GHG emissions, including all sources and sinks, were 35.1 million tonnes of CO_2 equivalents in 2022. The total emissions distribution among the CRF sectors from 1990 to 2022, 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_2 emissions[7] but not emissions and removals from land use, land-use change and forestry (LULUCF). The indirect CO_2 emissions are further described in chapter 9.

[7] Non-CO_2, carbon-containing gases (methane (CH_4), CO or NMVOC) will eventually be oxidised to CO_2 in the atmosphere. The CO_2 emissions formed are termed "indirect CO_2 emissions".

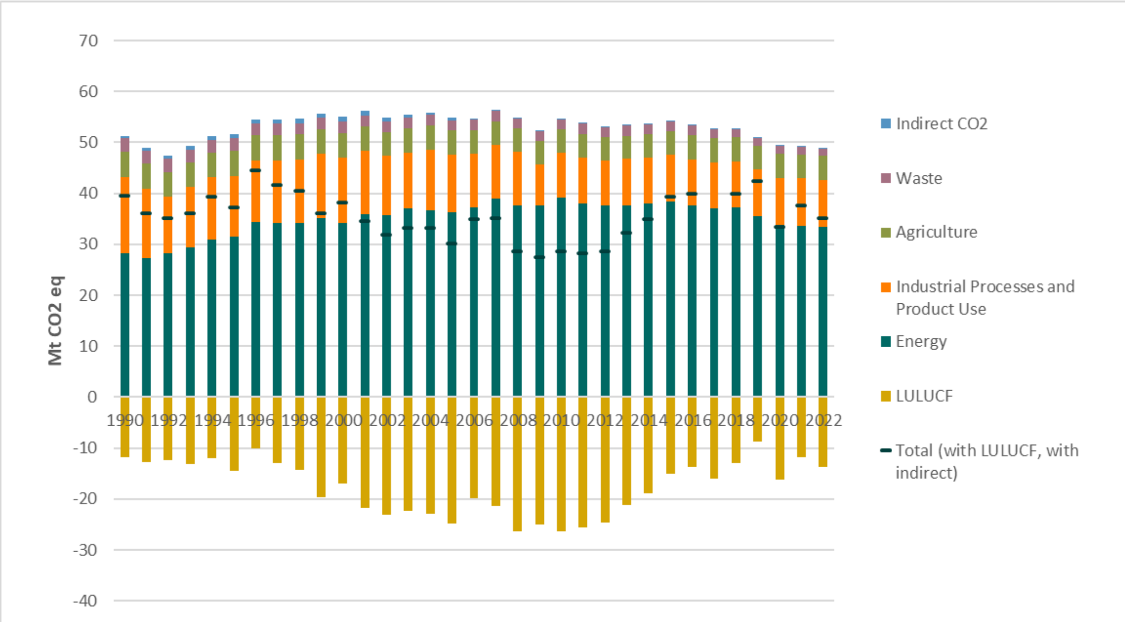


Figure 2.1: Total emissions of greenhouse gases by sources and removals from LULUCF in Norway, 1990-2022 (Mtonnes CO_2 equivalents). Source: Statistics Norway/Norwegian Environment Agency/Norwegian Institute of Bioeconomy Research

Table 2-1: Total emissions of greenhouse gases by sources and removals in Norway 1990-2022. Million tonnes of CO_2 equivalents.

Year	Energy	Industrial processes and product use	Agriculture	LULUCF	Waste	Indirect CO_2 emissions	Total with indirect CO_2 and without LULUCF	Total with indirect CO_2 and with LULUCF	Total without indirect CO_2 and without LULUCF	Total without indirect CO_2 and with LULUCF
1990	28.3	14.8	5.0	-11.8	2.7	0.5	51.3	39.5	50.8	39.0
1995	31.4	12.0	4.9	-14.5	2.6	0.8	51.7	37.1	50.9	36.4
2000	34.2	12.9	4.7	-17.0	2.3	0.9	55.0	38.0	54.1	37.1
2005	36.3	11.3	4.7	-24.8	2.0	0.4	54.8	30.0	54.4	29.6
2010	39.2	8.9	4.5	-26.3	2.0	0.2	54.7	28.4	54.6	28.3
2011	38.0	9.0	4.5	-25.6	2.1	0.2	53.8	28.2	53.6	28.1
2012	37.6	8.9	4.5	-24.6	2.0	0.1	53.2	28.5	53.0	28.4
2013	37.7	9.0	4.5	-21.2	2.0	0.2	53.4	32.2	53.2	32.0
2014	37.9	9.1	4.6	-18.9	1.9	0.2	53.8	34.9	53.6	34.8
2015	38.4	9.2	4.7	-15.1	1.9	0.2	54.3	39.3	54.1	39.1
2016	37.7	9.1	4.7	-13.7	1.8	0.2	53.5	39.8	53.3	39.6
2017	37.1	9.1	4.7	-16.0	1.7	0.2	52,7	36,8	52,6	36,6
2018	37.2	9.1	4.7	-13.0	1.7	0.2	52.8	39.8	52.7	39.7

2019	35.6	9.1	4.7	-8.8	1.6	0.2	51.1	42.3	50.9	42.2
2020	33.8	9.1	4.7	-16.1	1.6	0.2	49.4	33.3	49.3	33.1
2021	33.6	9.3	4.8	-11.7	1.5	0.1	49.3	37.5	49.1	37.4
2022	33.4	9.3	4.6	-13.7	1.4	0.1	48.9	35.1	48.8	35.0

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

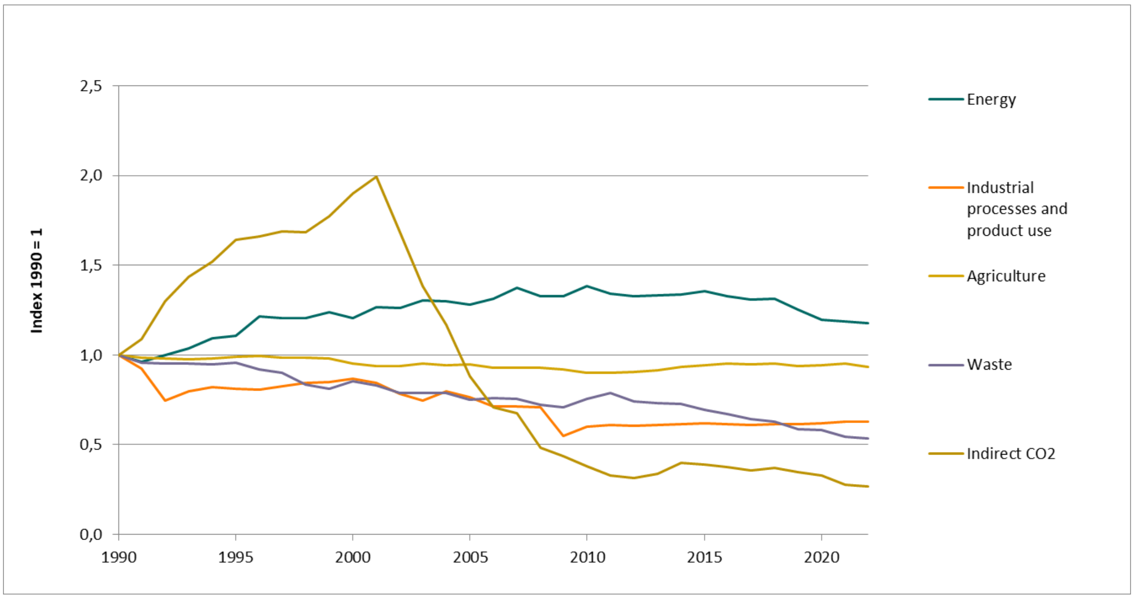


Figure 2.2: Changes in emissions of greenhouse gases, relative to 1990, by sectors, 1990-2022. The development in indirect CO2 emissions is also shown. Index 1990 = 1. Source: Statistics Norway/Norwegian Environment Agency.

Norway has experienced economic growth since 1990. In addition, the offshore petroleum sector has expanded significantly since then, reaching a peak in production in the early 2000s. Together this has resulted in higher CO_2 emissions from energy use, both in energy industries and transport. Emissions from the energy sector have increased by 18% from 1990 to 2022.

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 6.8% 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, emission trends are explained both by sector and by gas for the period 1990-2022.

2.2 Description of emission and removal trends by sector and gas

2.2.1 Trends by sector

The energy sector is by far the most important source of GHG emissions in Norway, contributing to 68% of the national GHG emissions in 2022, see Figure 2.3.

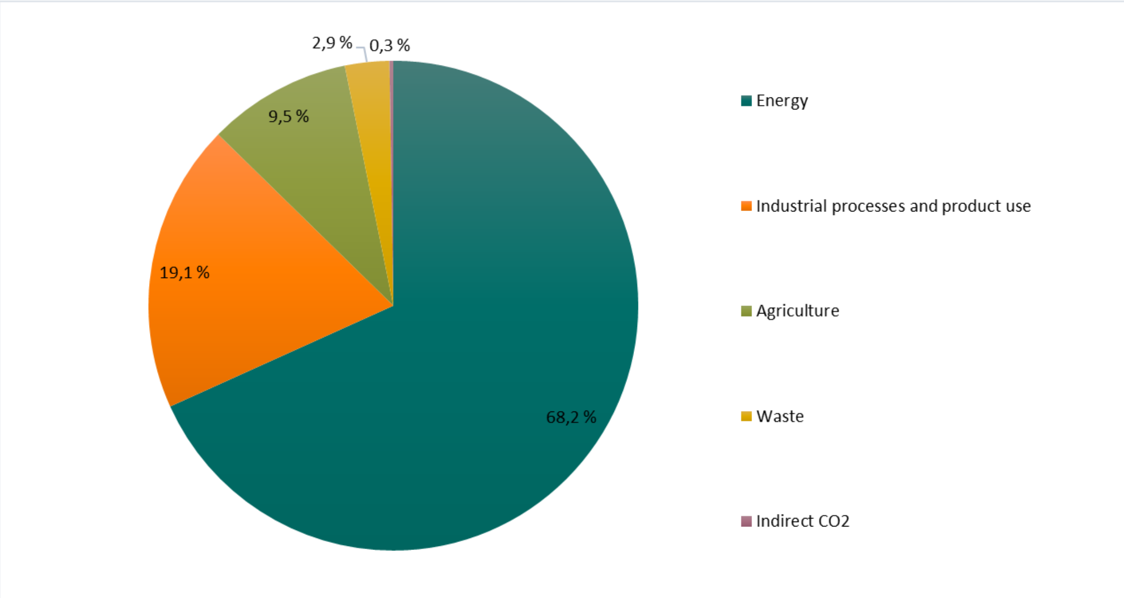


Figure 2.3: Distribution of GHG emissions (without LULUCF) in Norway in 2022 by sector. Indirect CO_2 emissions is also shown. Source: Statistics Norway/Norwegian Environment Agency.

Figure 2.4 displays GHG emissions trends by sectors between 1990 and 2022. 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[8], and fugitive emissions from fuels.

[8] 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).

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

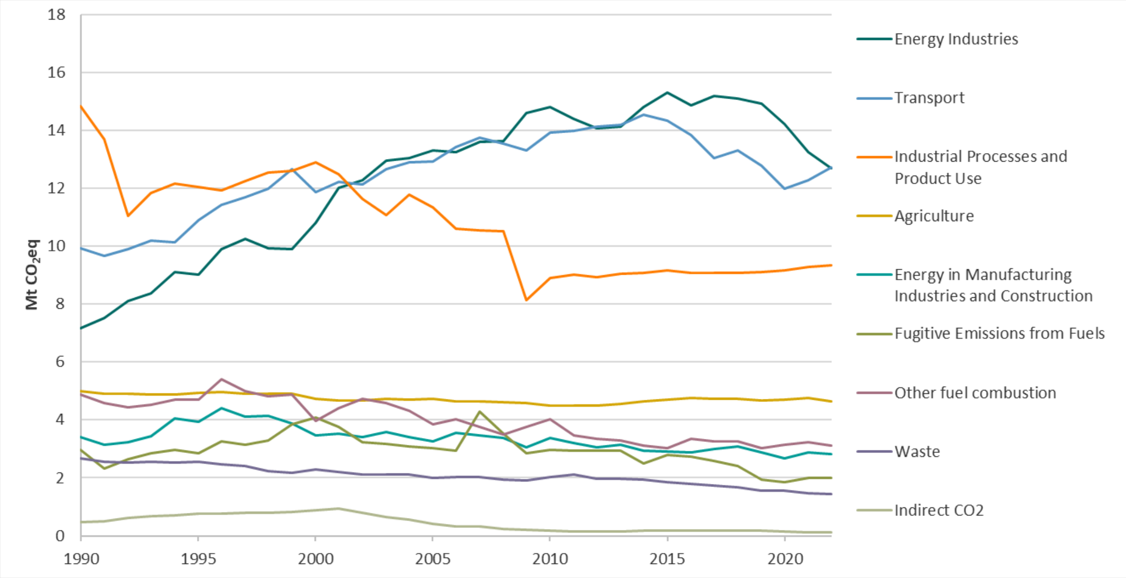


Figure 2.4: Development of emissions of all GHG (Mtonnes CO_2 eq.) from the different sectors (without LULUCF) 1990-2022. Indirect CO_2 emissions is also shown. Source: Statistics Norway/Norwegian Environment Agency.

2.2.1.1 Energy

The major sources of emissions within the energy sector are energy industries and transport, which both contributed to 38% of emissions from the energy sector in 2022, see Figure 2.5. The remaining emissions are shared between the categories other fuel combustion, energy use in manufacturing industries and construction and fugitive emissions from fuels.

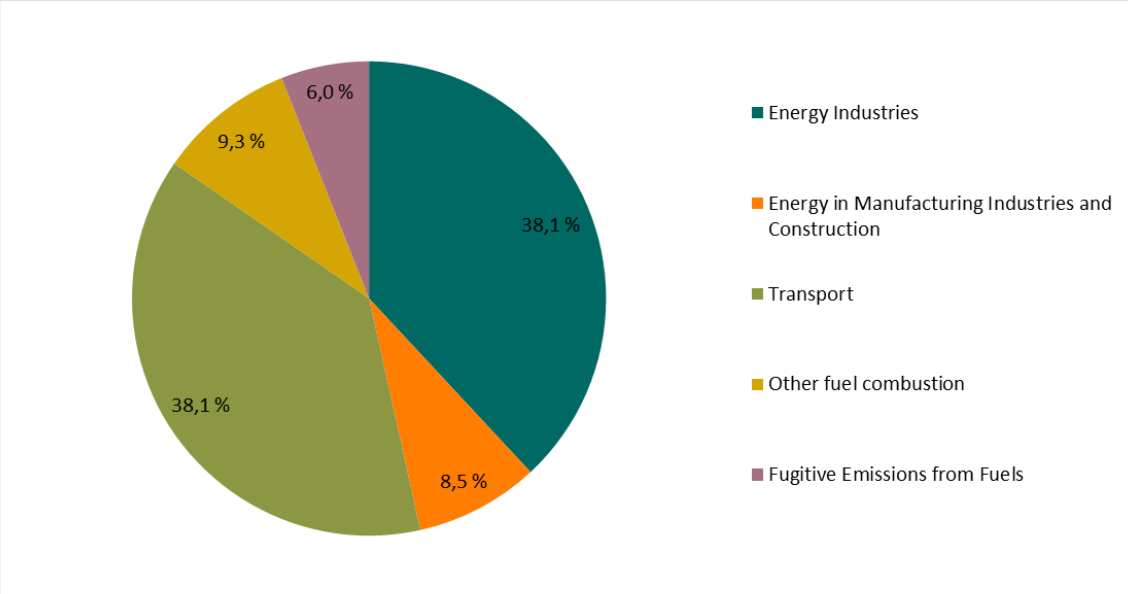


Figure 2.5: Greenhouse gas emissions in 2022 from the energy sector distributed among the different main source categories. Source: Statistics Norway/Norwegian Environment Agency.

Table 2-2: Emissions of greenhouse gases (Mtonnes CO_2 eq.) from the energy sector in Norway, 1990-2022.

Year	Energy Industries	Energy in Manufacturing Industries and Construction	Transport	Other fuel combustion	Fugitive Emissions from Fuels	CO_2 transport and storage	Total
1990	7.2	3.4	9.9	4.9	3.0	0.0	28.3
1995	9.0	3.9	10.9	4.7	2.8	0.0	31.4
2000	10.8	3.5	11.9	4.0	4.1	0.0	34.2
2005	13.3	3.2	12.9	3.8	3.0	0.0	36.3
2010	14.8	3.4	13.9	4.0	3.0	0.1	39.2
2011	14.4	3.2	14.0	3.5	2.9	0.1	38.0
2012	14.1	3.1	14.1	3.4	2.9	0.1	37.6
2013	14.1	3.2	14.2	3.3	2.9	0.0	37.7
2014	14.8	2.9	14.5	3.1	2.5	0.0	37.9
2015	15.3	2.9	14.3	3.0	2.8	0.0	38.4
2016	14.8	2.9	13.8	3.3	2.7	0.0	37.7
2017	15.2	3.0	13.1	3.2	2.6	0.0	37.1
2018	15.1	3.1	13.3	3.3	2.4	0.0	37.2
2019	14.9	2.9	12.8	3.0	1.9	0.0	35.6
2020	14.2	2.7	12.0	3.1	1.8	0.0	33.8
2021	13.3	2.9	12.3	3.2	2.0	0.0	33.6
2022	12.7	2.8	12.7	3.1	2.0	0.0	33.4

Source: Statistics Norway/Norwegian Environment Agency

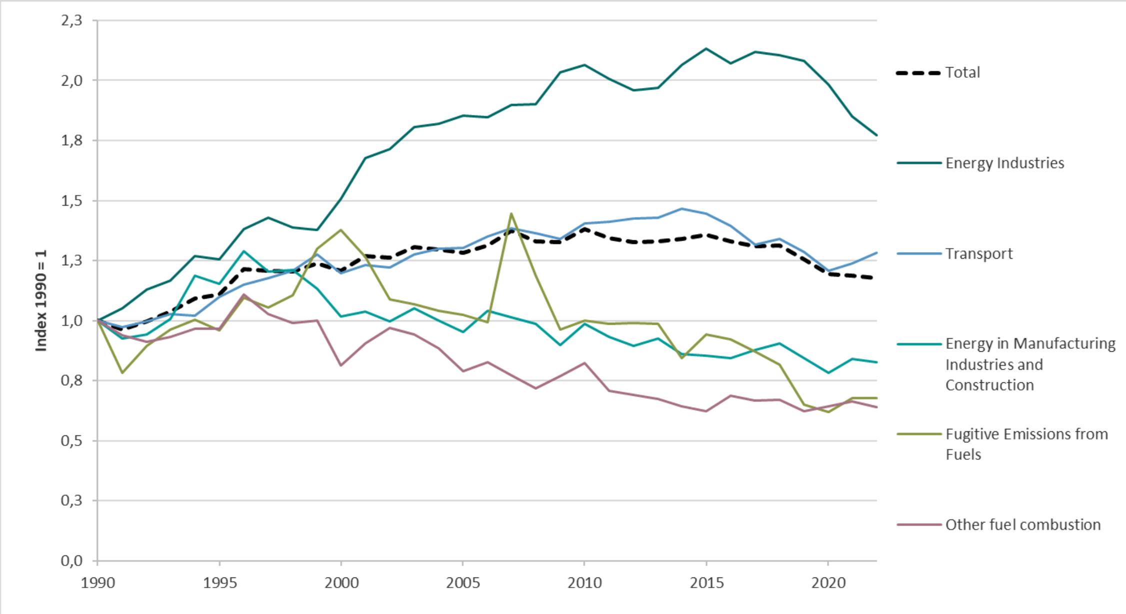


Figure 2.6: Development in emissions of greenhouse gases, relative to 1990, for the main sub-sectors within the energy sector, 1990-2022. Index 1990 = 1. Source: Statistics Norway/Norwegian Environment Agency.

The GHG emissions from the energy sector increased by 18% from 1990 to 2022, as shown in Figure 2.6. This was primarily due to increased activity within oil and gas extraction and transport, specifically road transportation. Since 2015, emissions have decreased by 13%. From 2021 to 2022, emissions decreased by 0.8%

The Norwegian electricity production is dominated by hydroelectric power. Thus, emissions from the category 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.

Emissions from fuel combustion within energy industries reached a peak in 2015, and for the last five years emissions have been declining. The growth until 2015 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. The reduction in emissions over the latest years can be explained by several factors, including the closure of a petroleum refining plant, an LNG plant being out of operation in 2021 and partly in 2020 and 2022, as well as the electrification of offshore platforms. Emissions were still 77% higher in 2022 than in 1990.

In 2022, emissions from energy combustion in oil and gas extraction contributed to 22% of the national GHG emissions. In 1990, the corresponding contribution was 12%.

Emissions from energy use in manufacturing industries and construction reported in the energy sector 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[9]. This applies particularly to production of metals, ammonia and petrochemicals. Off-road vehicles and other machinery accounted for 39% of the overall emissions from energy use in manufacturing and construction in 2022, which makes it the biggest emission category within this source. Other major contributing categories are non-metallic mineral production, food processing and beverages, as well as non-ferrous metals. Their contributions to total emissions from the category energy use in manufacturing industries and construction amounted to 24, 11 and 7,4% respectively.

Emissions from the manufacturing industries and construction in the energy sector decreased by 17% from 1990 to 2022, and by 1.6% from 2021 to 2022. In 2022, the emissions from this source category contributed to 5.8% of national GHG emissions.

Emissions from the transport category increased by 28% from 1990 to 2022, and by 3.6% from 2021 to 2022. The emissions reached a peak of 14.5 million tonnes in 2014. The share of transport in the national total GHG emissions has increased from 19% in 1990 to 26% in 2022. In 2022, road transportation accounted for 68% of emissions from the total transport emissions, while emissions from navigation and civil aviation accounted for 23% and 8%, 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 17% from 1990 to 2022, 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% from 2015 to 2022. In 2022 they contributed to 18% of the national GHG emissions. In addition to reduced activity, the stabilised and decreased emissions observed from 2007 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_2 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_2 emissions. In addition, the sales of electric vehicles have gradually increased since 2011 due to economic incentives. In 2022, 79% of new passenger cars sold

[9] 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.

and 23% of new light duty vehicles sold were electric. From 2021 to 2022, emissions from road transport were almost unchanged, with a small decline of 0.1%.

Navigation contributed to the national total GHG emissions by 6.0% in 2022. During the period 1990-2022, emissions have increased by 74%. Emissions from navigation increased mainly due to an increase of activity related to the oil and gas extraction sector.

Civil aviation contributed to 2.2% of the national GHG emissions in 2022. Emissions from civil aviation have increased by 53% since 1990. The substitution of older planes by new and more energy efficient planes has played an important role to limit the emission growth. The emissions increased by 33% from 2021 to 2022. The increase can be explained by travel restictions having been lifted after the covid19 pandemic.

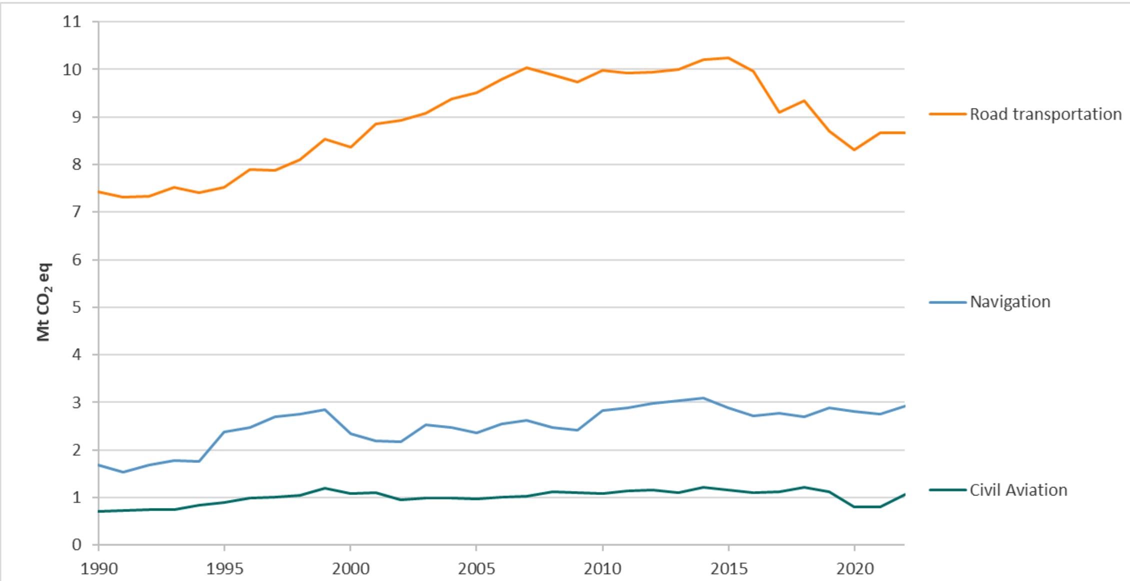


Figure 2.7: Emissions in million tonnes CO_2 equivalents from the most important modes of transport, 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

Table 2-3: Total emissions of greenhouse gases from the transport sector in Norway, 1990-2022. Million tonnes CO_2 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	14.5
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	13.3
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
2022	1.1	8.7	0.1	2.9	12.7

Source: Statistics Norway/Norwegian Environment Agency

The category “Other fuel combustion” includes, in particular, fuel combustion in agriculture, forestry and fisheries, residential sector and commercial/institutional sectors. The total emissions from this category were 3.1 million tonnes of CO_2 equivalents in 2022. Emissions decreased by 36% from 1990 to 2022 and by 3.7% from 2021 to 2022.

In 2022, GHG emissions from residential sources (stationary and mobile) accounted for 18% of emissions from the “Other fuel combustion” category. Emissions from the residential subsector have been reduced by 69% 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 2022, emissions from stationary combustion in the residential sector have decreased by 82%, mainly due to the electrification of heating infrastructure. Emissions from mobile combustion have declined by 8.4% in the same period, due to increased activity.

Emissions from commercial/institutional sources (mobile and stationary) have decreased by 5.7% since 1990. Emissions from commercial/institutional stationary sources decreased by 71% from 1990 to 2022, whereas emissions from commercial/institutional mobile sources increased by 128% between 1990 and 2022.

The sub-sector Fugitive emissions from fuels in Table 2-2 refers to emissions from oil and gas activities such as flaring of natural gas, leakages and venting of methane. Indirect CO_2 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 4.1% of the national GHG emissions in 2022 and to 6.0% of the GHG emissions within the energy sector. Fugitive emissions from fuels have decreased by 32% since 1990 and by 0.3% between 2021 and 2022.

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.

2.2.1.2 Industrial processes and product use

The industrial processes and other product use (IPPU) sector accounted for 19% of the national GHG emissions in 2022 (Figure 2.3). The emissions from this sector decreased by 37% from 1990 to 2022 and increased by 0.5% between 2021 and 2022.

Metal industry is the main source of emissions within the IPPU sector in the period 1990-2022. It contributed to 57% of the GHG emissions from the IPPU sector in 2022. The other main contributing sources in 2022 were chemical industry, mineral industry and product uses as substitutes for ODS (ozone depleting substances). They contributed to 20%, 11% and 8% of the GHG emissions from the IPPU sector, respectively.

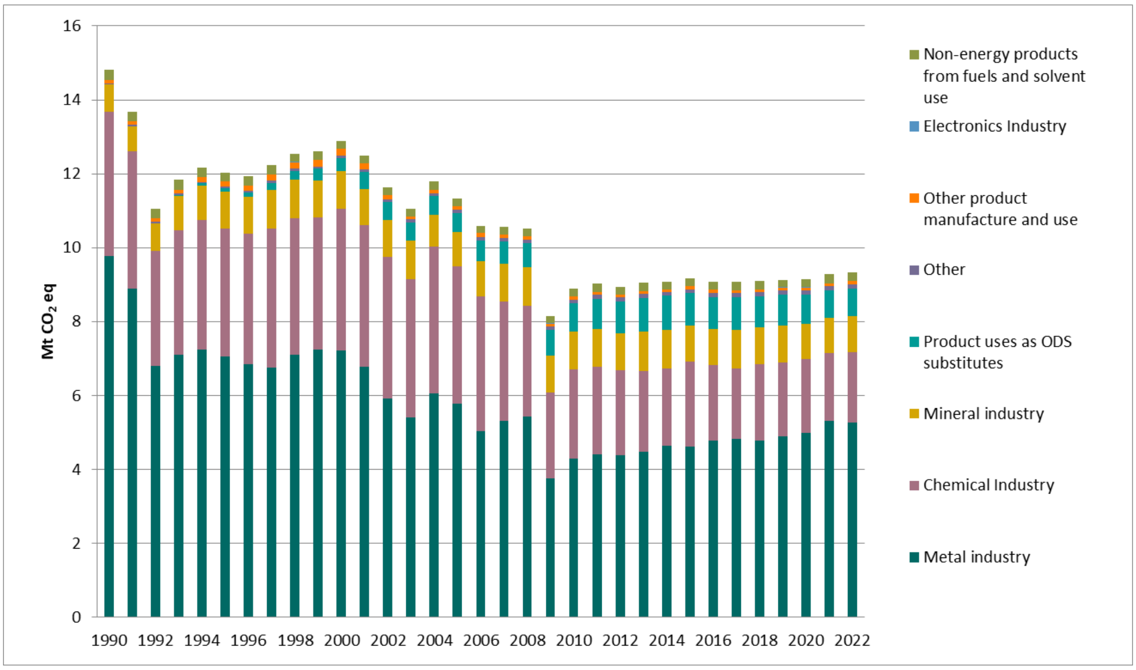


Figure 2.8: Total greenhouse gas emissions (Mtonnes CO_2 eq.) in the IPPU sub-sector in Norway, 1990-2022[10]. Source: Statistics Norway/Norwegian Environment Agency.

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.

11% of national GHG emissions came from the metal industry in the IPPU sector in 2022, whose emissions decreased by 0.8% from 2021 to 2022.

The largest contributors to the GHG emissions from metal production in 2022 are productions of ferroalloys and aluminium. Emissions from those productions constituted 97% of emissions from the metal industry in 2022. The large decrease in emissions in 2009 reflects low production levels of ferroalloys, due to lower economic activity and economic recession.

In 1990, PFC emissions from aluminium production contributed to 6.8% of the national GHG emissions, while in 2022, it has been reduced to 0.2%. Emissions of PFCs from

[10] Under Other production, Norway reports the two source categories: pulp and paper and food and drink.

aluminium production have decreased by 97% since 1990, and between 2021 and 2022 emissions decreased by 45%.

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_2 equivalents in 2022 and accounted for 5.8% of the national total GHG emissions. Emissions from production of ferroalloys increased by 10% from 1990 to 2022, with a 1.2% increase from 2021. The large increase in emissions from 2009 to 2010 (50%) is due to the low production level in 2009.

Table 2-4: Total greenhouse gas emissions (Mtonnes CO_2 eq.) from the IPPU sub-sectors in Norway, 1990-2022.

Year	Mineral industry	Chemical Industry	Metal industry	Non-energy products from fuels and solvent use	Electro-nics Industry	Product uses as ODS substitutes	Other product manu-facture and use	Other	Total
1990	0.7	3.9	9.8	0.3	-	0.0	0.1	0.0	14.8
1995	1.0	3.5	7.1	0.2	0.0	0.1	0.1	0.0	12.0
2000	1.0	3.8	7.2	0.2	0.0	0.4	0.2	0.1	12.9
2005	0.9	3.7	5.8	0.2	0.0	0.5	0.1	0.1	11.3
2010	1.0	2.4	4.3	0.2	0.0	0.8	0.1	0.1	8.9
2011	1.0	2.4	4.4	0.2	0.0	0.8	0.1	0.1	9.0
2012	1.0	2.3	4.4	0.2	0.0	0.9	0.1	0.1	8.9
2013	1.1	2.2	4.5	0.2	0.0	0.9	0.1	0.1	9.0
2014	1.1	2.1	4.6	0.2	0.0	0.9	0.1	0.1	9.1
2015	1.0	2.3	4.6	0.2	0.0	0.9	0.1	0.1	9.2
2016	1.0	2.0	4.8	0.2	0.0	0.9	0.1	0.1	9.1
2017	1.0	1.9	4.8	0.2	-	0.9	0.1	0.1	9.1
2018	1.0	2.1	4.8	0.2	0.0	0.8	0.1	0.1	9.1
2019	1.0	2.0	4.9	0.2	0.0	0.8	0.1	0.1	9.1
2020	1.0	2.0	5.0	0.2	0.0	0.8	0.1	0.1	9.2
2021	0.9	1.8	5.3	0.2	0.0	0.7	0.1	0.1	9.3
2022	1.0	1.9	5.3	0.2	0.0	0.7	0.1	0.1	9.3

Source: Statistics Norway/Norwegian Environment Agency

In 1990, SF_6 from magnesium foundries accounted for 4.1% of the national total GHG emissions. Emissions decreased until the closure of all plants in 2007. Reductions in SF_6 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_2O from nitric acid production and CO_2 from production of ammonia and carbides. The GHG emissions from this sub-sector amounted to 1.9 million tonnes of CO_2 equivalents in 2022, which represented 3.9% of the national GHG emissions. Emissions have decreased by 52% since 1990, mainly due to the reduction of emissions from the production of nitric acid, ammonia, and carbides. Emissions have increased by 2.8% from 2021 to 2022.

The emissions from mineral industry were 1 million tonnes in 2022, which accounted for 2% of the national GHG emissions. Emissions increased by 36% from 1990 to 2022, mainly due to the increase of cement and lime production. The emissions from the mineral industry increased by 5.7% from 2021 to 2022.

In 2022, the CO_2 process emissions from cement production were 1.5% of the national GHG emissions. They have increased by 12% since 1990, due to increased production of clinker. From 2021 to 2022 emissions from cement production increased by 1.7%.

2.2.1.3 Agriculture

In 2022, 9.5% of the national GHG emissions originated from agriculture, corresponding to 4.6 million tonnes of CO_2 equivalents. Emissions from agriculture have decreased by 6.8% since 1990 and by 2.3% between 2021 and 2022.

The largest sources of GHGs within the agriculture sector are enteric fermentation (CH_4) and agricultural soils (N_2O). In 2022, these categories represented 52% and 33% of the emissions from the agriculture sector, respectively, while manure management represented 12%.

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 2.4 million tonnes CO_2 equivalents in 2022, corresponding to 4.9% of the national GHG emissions. This category constituted 86% of the overall CH_4 emissions from agriculture in 2022.

The emissions of N_2O from agricultural soils amounted to 1.5 million tonnes CO_2 equivalents in 2022. This accounted for 70% of the national N_2O emissions in 2022, and 3.1% of the national GHG emissions.

In 2022, emissions of CH_4 from manure management amounted to 0.4 million tonnes CO_2 equivalents and emissions of N_2O from manure management amounted to 0.2 million tonnes CO_2 equivalents. Together this accounted for 1.1% of the Norwegian GHG emissions.

Liming of agricultural soils and lakes is a source of emissions of CO_2 and corresponded to 2.6% of the agricultural GHG emissions in 2022. These emissions have decreased with 47% since 1990, mainly because less liming occurs on agricultural lands.

Table 2-5: Greenhouse gas emissions (Mtonnes CO_2 eq.) from the agricultural sub-sectors in Norway, 1990-2022. Urea application is in ktonnes CO_2 eq.

Year	Enteric Fermentation	Manure Management	Agricultural Soils	Field burning of agricultural residues	Liming	Urea application (kt)	Total
1990	2.6	0.5	1.6	0.0	0.2	0.6	5.0
1995	2.6	0.5	1.6	0.0	0.2	0.6	4.9
2000	2.5	0.5	1.6	0.0	0.1	0.1	4.7
2005	2.5	0.5	1.6	0.0	0.1	0.1	4.7
2010	2.4	0.6	1.4	0.0	0.1	0.3	4.5
2011	2.4	0.6	1.5	0.0	0.1	0.3	4.5
2012	2.4	0.6	1.5	0.0	0.1	0.2	4.5
2013	2.4	0.6	1.5	0.0	0.1	0.2	4.5
2014	2.4	0.6	1.6	0.0	0.1	0.2	4.6
2015	2.5	0.6	1.6	0.0	0.1	0.2	4.7
2016	2.5	0.6	1.6	0.0	0.1	0.2	4.7
2017	2.5	0.6	1.5	0.0	0.1	0.1	0.0
2018	2.5	0.6	1.5	0.0	0.1	0.1	4.7
2019	2.4	0.6	1.6	0.0	0.1	0.1	4.7
2020	2.4	0.6	1.6	0.0	0.1	0.1	4.7
2021	2.5	0.6	1.6	0.0	0.1	0.1	4.8
2022	2.4	0.6	1.5	0.0	0.1	0.2	4.6

Source: Statistics Norway/Norwegian Environment Agency

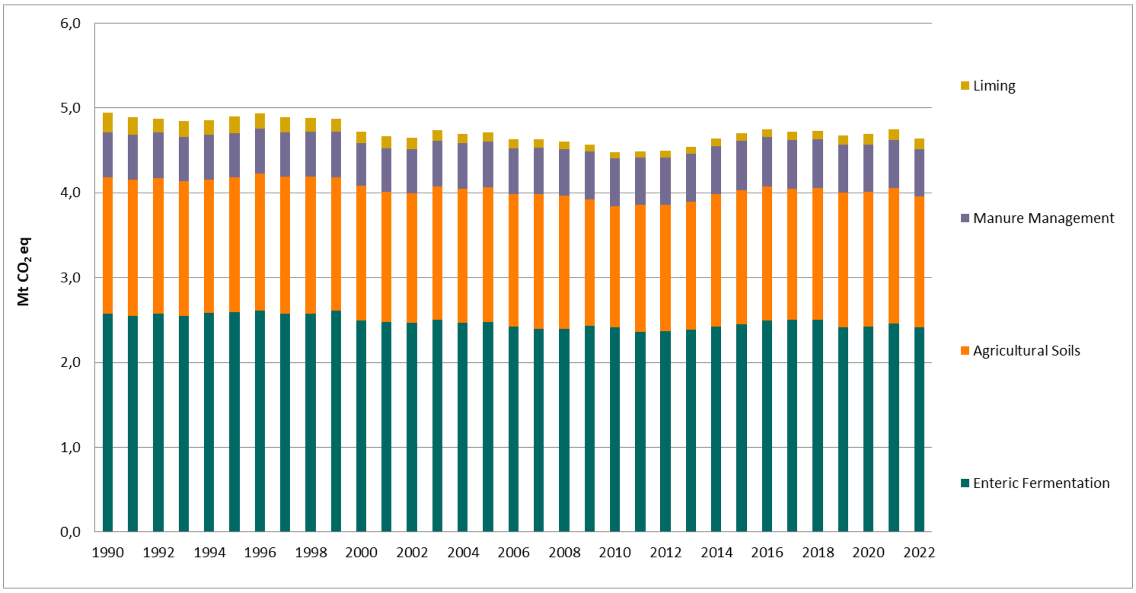


Figure 2.9: Total greenhouse gas emissions (Mtonnes CO_2 eq.) in the agriculture sub-sectors in Norway, 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

2.2.1.4 Land Use, Land-Use Change and Forestry (LULUCF)

The LULUCF sector includes both emissions of greenhouse gasses (GHG) CO_2, N_2O and CH_4 to the atmosphere, and removal of atmospheric CO_2. The balance of the two is the net emissions or removals in the LULUCF sector.

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

The area distribution of the land-use categories for Norway in 1990 and 2022 is illustrated in Figure 2.10. The figure shows that the net changes in land-area distribution in Norway from 1990 to 2022 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.

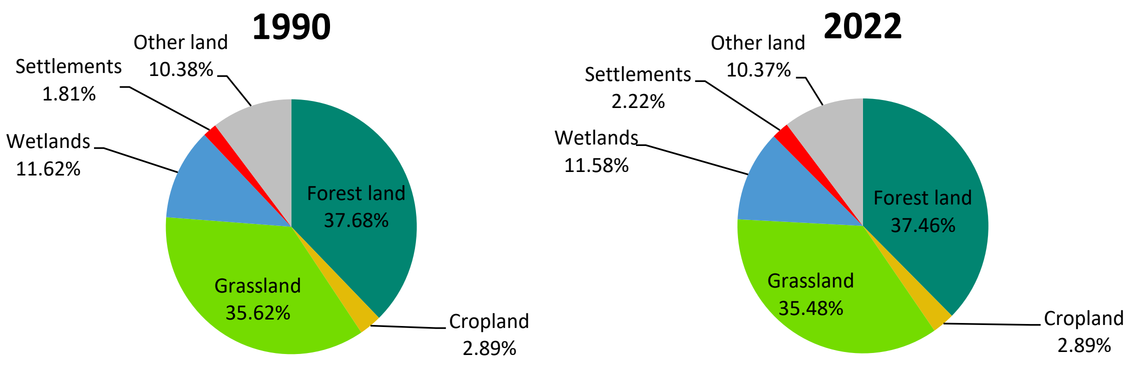


Figure 2.10: Area (%) distribution between the IPCC land-use categories, 1990 and 2022. Source: The Norwegian Institute of Bioeconomy Research.

In 2022, the net removal in the LULUCF sector was 13.7 million tonnes CO_2 equivalents, which corresponds to about 28% of the national GHG emissions (from all other sectors than LULUCF) that year. Figure 2.11 illustrates net emissions and removals of CO_2 equivalents by land-use category. Forest land, grasslands and harvested wood products had net removals in 2022, while emissions came from cropland, settlements and wetlands (about 4.7 million tonnes of CO_2 equivalents). Forest land was the major contributor to the net sequestration of CO_2 in the sector, with total net removals of 17.9 million tonnes of CO_2.

Over the years, the LULUCF sector has seen noticeable changes. For forest land remaining forest land, the average carbon removals by living biomass have decreased from 1990 to 2022. Historically, we can first observe an increase in carbon stocks, as a result of an active forest management policy implemented in the decades after the Second World War, which led to an increased area of productive forest, as well as higher productivity in already existing forests. The stocks were further benefited by an annual felling lower than the annual increment. However, a large proportion of these forests are beginning to mature and hence reduce their increment. An increase in natural mortality in the last decade is also impacting the stocks. These factors lead to a future decline that is already apparent in the data.

Deforestation has increased, with land-use changes to grasslands and croplands contributing to most of the increased emissions. DOM and living biomass make up a major part of the emissions from deforestation.

Cropland remaining cropland drained organic soil is the largest emission source and has continued to increase, on average, from 1990 to 2022.

Reductions in emissions are small. 1990 to 2022 average declining trends are observed for the land-use change categories wetland converted to cropland, forest land converted to settlements, forest land converted to cropland, and grasslands remaining grasslands.

Although some categories under HWP have gone from a net sink to net emission source, HWP still contributes with net removals to the LULUCF sector.

It should be noted that, in the LULUCF sector, comparison between two points in time do not always provide a full picture of the overall trends. For example, deforestation results in large instantaneous emissions, yet very few plots are observed per year. Thus, large fluctuation in emissions will appear annually for many land-use change categories.

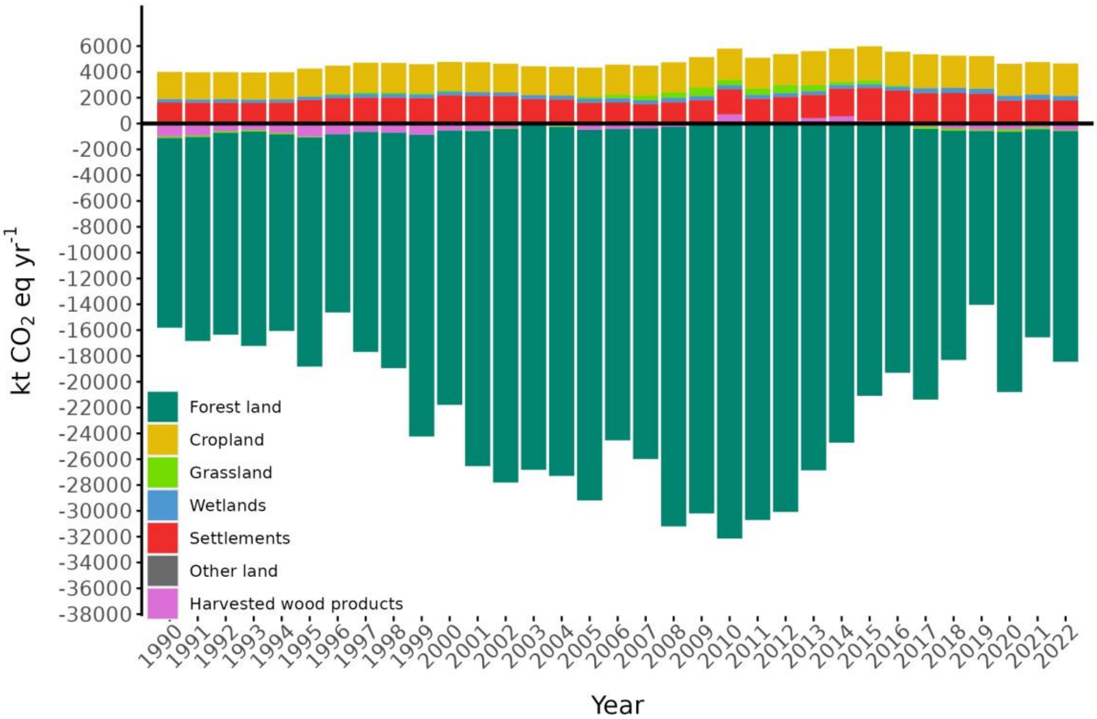


Figure 2.11: Net CO_2 emissions and removals (kt CO_2 equivalents per year) from the LULUCF sector by land-use category from 1990 to 2022, including emissions of N_2O and CH_4. Negative values are net removals, positive values are net emissions. Source: Norwegian Institute of Bioeconomy Research.

2.2.1.5 Waste

The waste sector, with emissions of 1.4 million tonnes of CO_2 equivalents in 2022, accounted for 2.9% of the national GHG emissions. This sector includes emissions from landfills (CH_4), wastewater handling (CH_4 and N_2O), biological treatment of solid waste and small-scale waste incineration (CO_2 and CH_4). 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 61% of the sector's total emissions in 2022. Wastewater handling accounted for 19%, waste incineration for 15%, and biological treatment of solid waste accounted for 4.6%.

GHG emissions from the waste sector have generally decreased since 1990, see Figure 2.12.

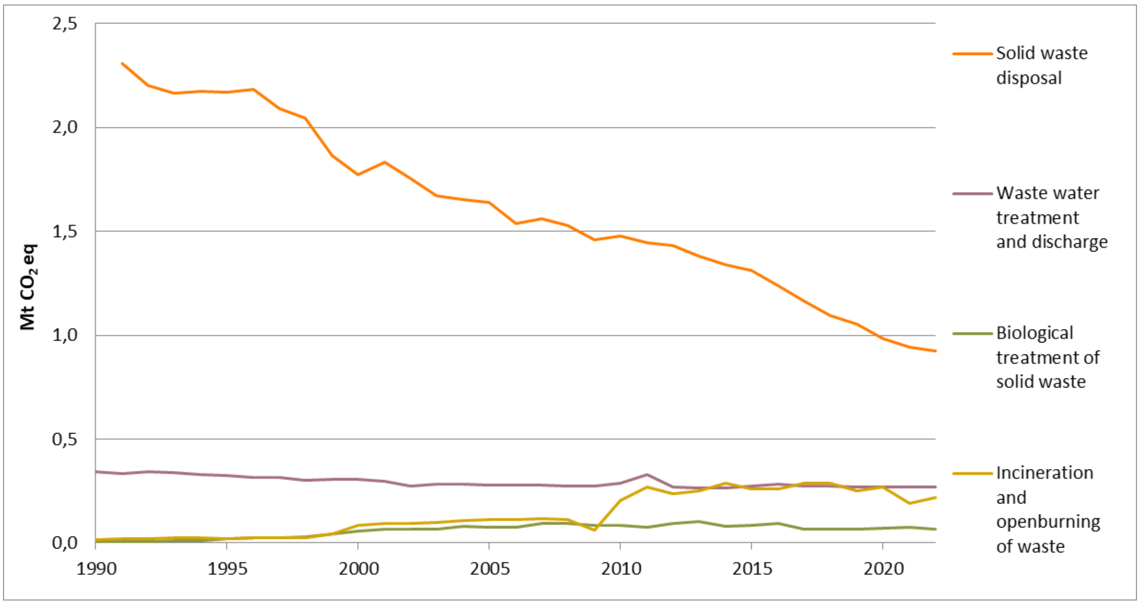


Figure 2.12: Total emissions of greenhouse gases (Mtonnes CO_2 eq.) in Norway from the waste categories, 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

Table 2-6: Emissions (Mtonnes CO_2 eq.) from the waste sub-sectors in Norway, 1990-2022. Incineration and open burning of waste is presented in ktonnes CO_2 eq.

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	1.6
2021	0.9	0.1	0.2	0.3	1.5
2022	0.9	0.1	0.2	0.3	1.4

Source: Statistics Norway/Norwegian Environment Agency

In 2022, emissions were 46% lower than in 1990 and 1.6% lower than in 2021. Methane emissions from solid waste disposal (landfills) decreased by 62% since 1990.

The total amount of waste generated increased by 70% from 1995 to 2022, 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.

2.2.2 Trends by gas

As shown in Figure 2.13, CO_2 is by far the largest contributor to the total GHG emissions, followed by CH_4, N_2O, and the fluorinated gases (PFCs, SF_6 and HFCs). The relative share of the gases has been quite stable since 2010. However, the relative share of CO_2 increased steadily from 68% in 1990 up to 83% in 2010.

Table 2-7: Emissions of greenhouse gases in Norway, 1990-2022.

Gas	CO_2	CH_4	N_2O	PFC	SF_6	HFC
Year	**Mt**	**kt**		**kt CO_2 eq**		
1990	35.0	242.3	14.4	3499.8	2163.0	0.0
1995	38.5	249.5	13.0	2078.9	597.6	92.5
2000	42.1	239.3	13.4	1364.1	918.6	359.8
2005	43.3	217.1	14.2	858.2	305.9	521.8
2010	45.6	206.1	8.7	214.3	70.5	761.1
2011	44.7	200.6	8.8	236.1	55.1	822.6
2012	44.2	196.9	8.8	180.3	54.1	869.4
2013	44.5	194.5	8.7	162.8	56.9	925.8
2014	45.0	192.8	8.8	160.9	50.1	914.1
2015	45.5	192.5	8.9	131.6	69.4	871.6
2016	44.7	191.4	8.7	167.4	62.8	878.9
2017	44.2	188.3	8.4	117.8	57.7	893.7
2018	44.4	185.3	8.4	133.1	55.2	833.9
2019	42.8	177.4	8.5	157.4	69.8	831.0
2020	41.2	178.0	8.4	145.2	75.7	776.0
2021	41.0	177.5	8.4	222.8	71.9	743.2
2022	40.8	175.8	8.3	122.2	70.9	746.8

Source: Statistics Norway/Norwegian Environment Agency

Table 2-8: Emissions in Mtonnes CO_2 equivalents and changes in per cent for each greenhouse gas.

Year	CO_2	CH_4	N_2O	PFCs	SF_6	HFCs	Total with indirect CO_2 and without LULUCF
1990	35.0	6.8	3.8	3.5	2.2	0.00005	51.3
2021	41.0	5.0	2.2	0.2	0.1	0.7	49.3
2022	40.8	4.9	2.2	0.1	0.1	0.7	48.9
Changes 1990-2022	16.6%	-27.5%	-42.0%	-96.5%	-96.7%	1503091.8%	-4.6%
Changes 2021-2022	-0.5%	-1.0%	-0.4%	-45.1%	-1.4%	0.5%	-0.8%

Source: Statistics Norway/Norwegian Environment Agency

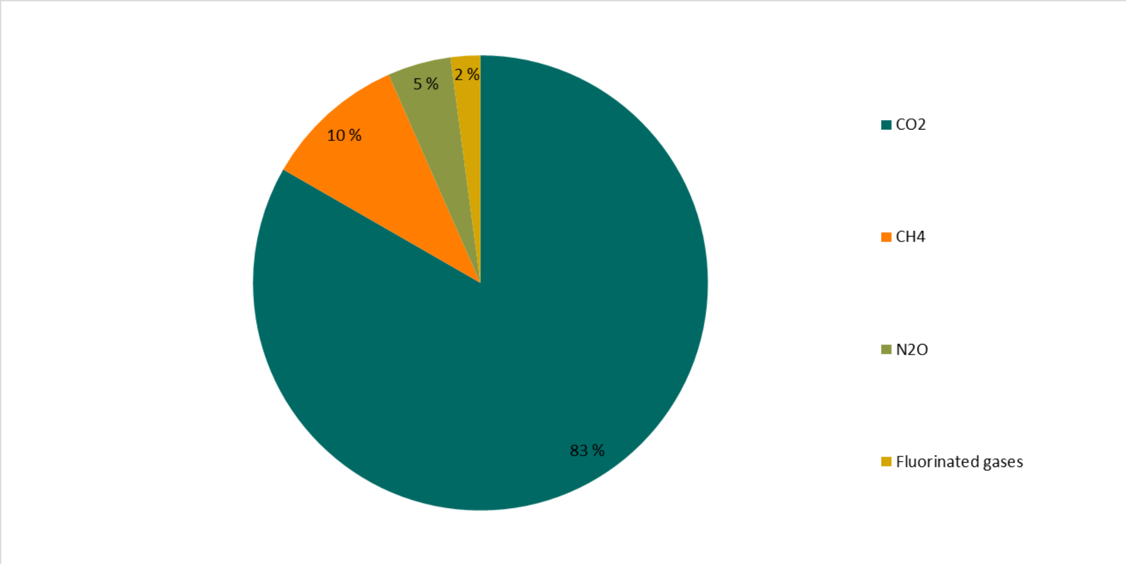


Figure 2.13: Distribution of emissions of greenhouse gases in Norway by gas (in CO_2 equivalents.), 2022. Source: Statistics Norway/Norwegian Environment Agency.

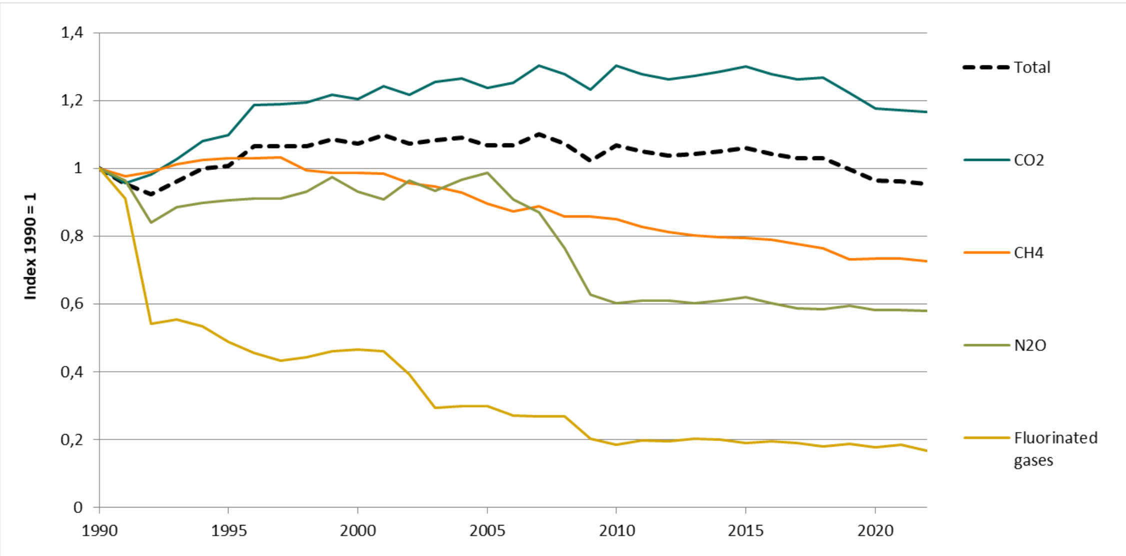


Figure 2.14: Changes in emissions of greenhouse gases, relative to 1990, by gas, 1990-2022. 'CO_2' and 'Total' includes indirect CO_2. Index 1990 = 1. Source: Statistics Norway/Norwegian Environment Agency.

As presented in Table 2-7 and

Table 2-8, CO_2 emissions increased significantly from 1990 to 2022 with 5.8 million tonnes. Emissions of CH_4 and N_2O decreased by 1.9 and 1.6 million tonnes CO_2 equivalents, respectively. During the same period, PFCs and SF_6 emissions significantly decreased with 3.4 and 2.1 million tonnes CO_2 equivalents, respectively, while HFCs has increased from almost 0 to 0.7 million tonnes CO_2 equivalents.

The fluorocarbons constituted a larger share of the GHG emission total in the early 1990s than in 2022, while CO_2 represented a smaller share in 1990 than in 2022.

Figure 2.14 shows that the overall increasing emission trend of CO_2 has been offset by decreased emissions of fluorinated gases (SF_6 and PFCs).

2.2.2.1 Carbon dioxide (CO_2)

The Norwegian CO_2 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.

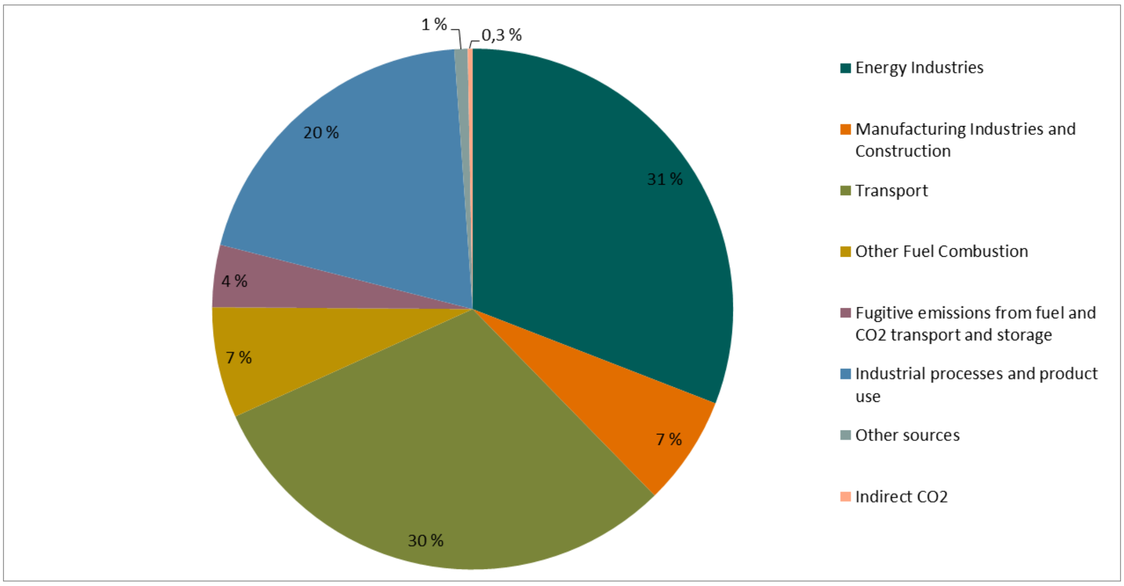


Figure 2.15: Distribution of CO_2 emissions in Norway by various source categories in 2022 (by mass). Source: Statistics Norway/Norwegian Environment Agency.

Table 2-9: CO2 emissions (million tonnes) from different source categories, 1990-2022.

Year	Energy Indu-stries	Manu-facturing Industries and Con-struction	Trans-port	Other Fuel Combustion	Fugitive emissions from fuel and CO_2 transport and storage	Industrial processes and product use	Indirect CO_2	Other sources	Total with indirect CO_2 and without LULUCF
1990	7.1	3.4	9.8	4.4	2.4	7.3	0.5	0.2	35.0
1995	9.0	3.9	10.7	4.2	2.0	7.7	0.8	0.2	38.5
2000	10.8	3.4	11.7	3.4	3.1	8.6	0.9	0.2	42.1
2005	13.2	3.2	12.8	3.4	2.3	7.8	0.4	0.2	43.3
2010	14.7	3.3	13.7	3.6	2.5	7.3	0.2	0.3	45.6
2011	14.3	3.1	13.8	3.1	2.5	7.4	0.2	0.3	44.7
2012	14.0	3.0	13.9	3.0	2.5	7.4	0.1	0.3	44.2
2013	14.0	3.1	13.9	3.0	2.5	7.5	0.2	0.3	44.5
2014	14.7	2.9	14.3	2.8	2.1	7.6	0.2	0.4	45.0
2015	15.2	2.9	14.1	2.7	2.4	7.7	0.2	0.3	45.5
2016	14.8	2.8	13.6	3.1	2.3	7.7	0.2	0.3	44.7
2017	15.1	2.9	12.8	0.0	0.0	7.7	0.2	0.0	0.0
2018	15.0	3.0	13.1	3.0	2.0	7.8	0.2	0.4	44.4
2019	14.8	2.8	12.5	2.8	1.5	7.8	0.2	0.4	42.8
2020	14.1	2.6	11.8	2.8	1.4	7.9	0.2	0.4	41.2
2021	13.2	2.8	12.1	3.0	1.6	8.0	0.1	0.3	41.0
2022	12.6	2.8	12.5	2.8	1.6	8.1	0.1	0.3	40.8

Source: Statistics Norway/Norwegian Environment Agency

Since 1990, the total emissions of CO_2 have increased by 17%, equalling 5.8 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 2022, the total Norwegian emissions of CO_2 were 40.8 million tonnes. There has been a downward trend in emissions since 2010, totalling 11%, or 4.8 million tonnes, by 2022. Between 2021 and 2022, the emissions decreased by 0.5% or 0.2 million tonnes.

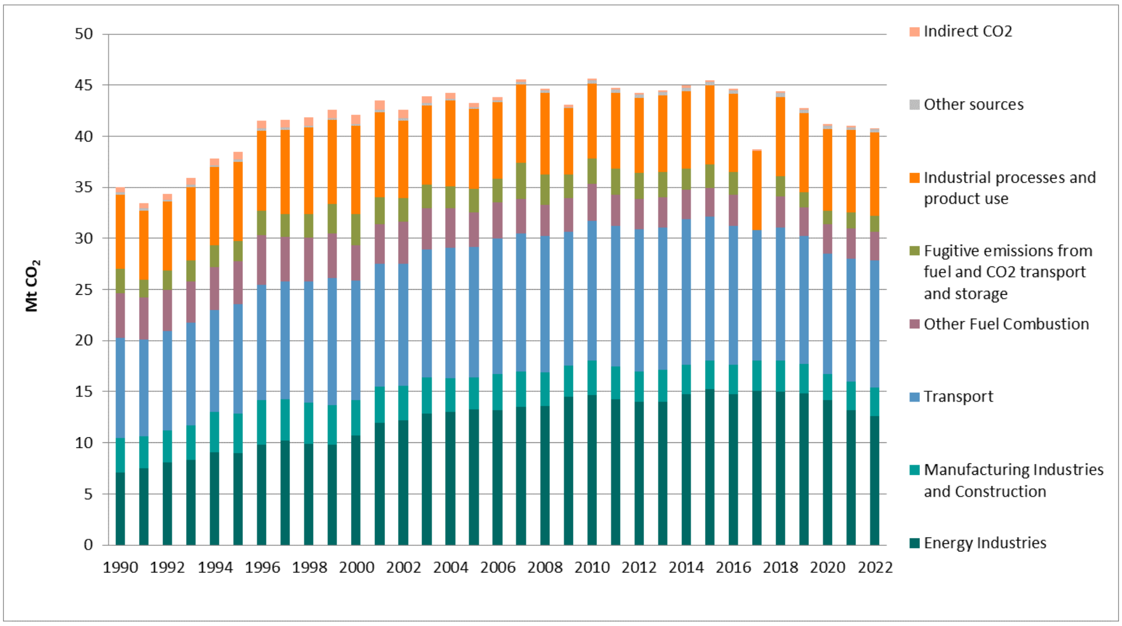


Figure 2.16: CO_2 emissions (Mtonnes) in Norway, 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

CO_2 emissions from energy industries have increased by 77% since 1990 as a result of large increases in production volume of oil and gas and the export of natural gas in pipelines. In 2022, emissions from energy industries decreased by 0.6 million tonnes, or 4.2%, compared to 2021.

CO_2 emissions from transport have increased by 28% since 1990 and contributed to 31% of the total CO_2 emissions in 2022. CO_2 emissions from this sector is dominated by road transportation which in 2022 accounted for 69% of the CO_2 emissions from transport.

CO_2 emissions from road transportation increased by 17% between 1990 and 2022, although emissions from personal cars decreased by 20%. CO_2 emissions from road transportation was almost unchanged from 2021 to 2022.

CO_2 emissions from industrial processes have increased by 12% since 1990 and contributed to 20% of total CO_2 emissions in 2022. Metal production is the biggest source and accounted for 63% of the CO_2 emissions from industrial processes in 2022.

2.2.2.2 Methane (CH_4)

In 2022, 57% of methane emissions originated from agriculture, 19% from the energy sector and 24% 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.

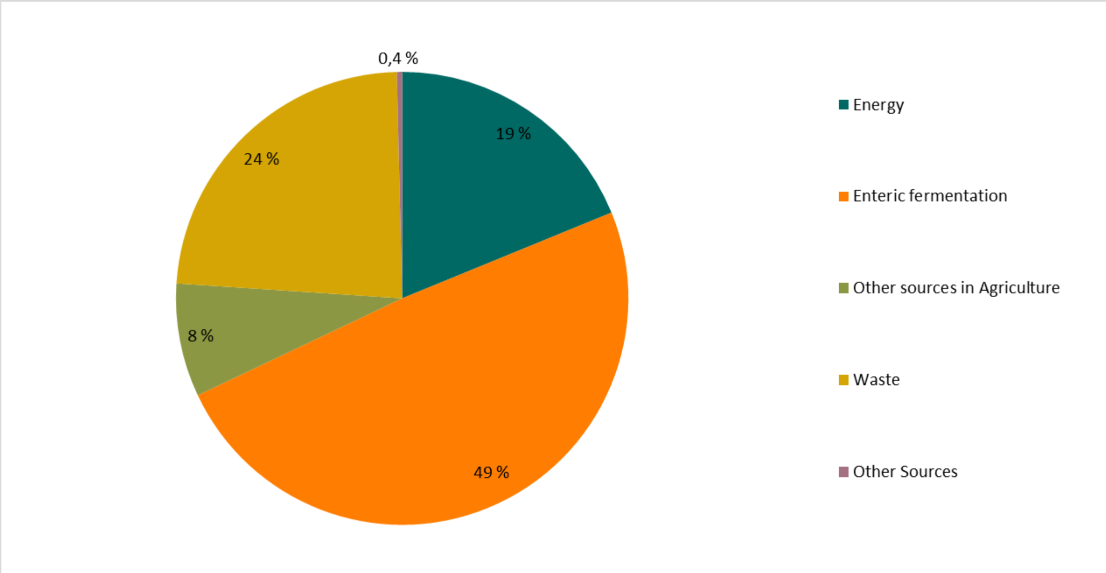


Figure 2.17: Distribution of Norwegian CH_4 emissions by major sources in 2022. Source: Statistics Norway/Norwegian Environment Agency.

Table 2-10: Emissions of CH_4 (ktonnes) in Norway, 1990-2022.

Years	Energy	Enteric fermentation	Other sources in Agriculture	Waste	Other Sources	Total without LULUCF
1990	41.3	91.9	14.5	93.5	1.1	242.3
1995	53.0	92.5	14.1	88.9	1.1	249.5
2000	59.1	89.2	13.3	76.4	1.3	239.3
2005	48.1	88.4	14.0	65.6	1.1	217.1
2010	41.4	86.3	14.7	62.9	0.9	206.1
2011	37.4	84.3	14.4	63.6	0.9	200.6
2012	37.0	84.5	14.5	60.2	0.8	196.9
2013	35.1	85.3	14.6	58.7	0.8	194.5
2014	33.6	86.5	14.9	57.0	0.8	192.8
2015	34.3	87.5	15.0	54.7	0.9	192.5
2016	33.5	89.2	15.2	52.7	0.8	191.4
2017	33.8	89.3	15.0	49.3	0.0	188.3
2018	32.1	89.5	15.0	47.9	0.9	185.3
2019	30.7	86.1	14.5	45.3	0.9	177.4
2020	32.5	86.4	14.3	44.0	0.8	178.0

2021	31.3	87.6	14.5	43.3	0.7	177.5
2022	33.1	86.4	14.2	41.4	0.7	175.8

Source: Statistics Norway/Norwegian Environment Agency

The total methane emissions decreased by 1% from 2021 to 2022. Since 1990, CH_4 emissions have decreased by 28%.

Table 2-10 and Figure 2.18 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.

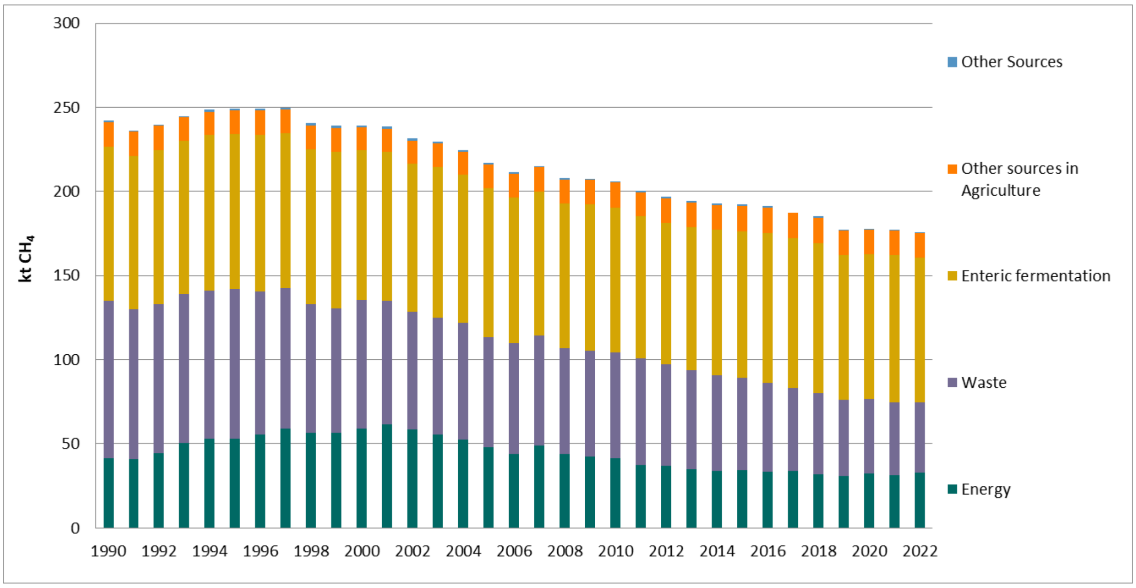


Figure 2.18: CH_4 emissions (ktonnes) in Norway, 1990-2022, without LULUCF. Source: Statistics Norway/Norwegian Environment Agency.

2.2.2.3 Nitrous oxide (N_2O)

Figure 2.19 shows that, in 2022, 77% of the Norwegian N_2O emissions are of agricultural origin, agricultural soils being the most prominent contributor within the agriculture sector. Industrial processes (almost entirely fertilizer and nitric acid production) were the second biggest contributor, accounting for 11% of the N_2O emissions in 2022. The energy sector, with transport being the largest contributor, accounted for 9.2%. and the waste sector for

2.6%. Emissions are dominated by road transport in the energy sector and by wastewater treatment and discharge in the waste sector.

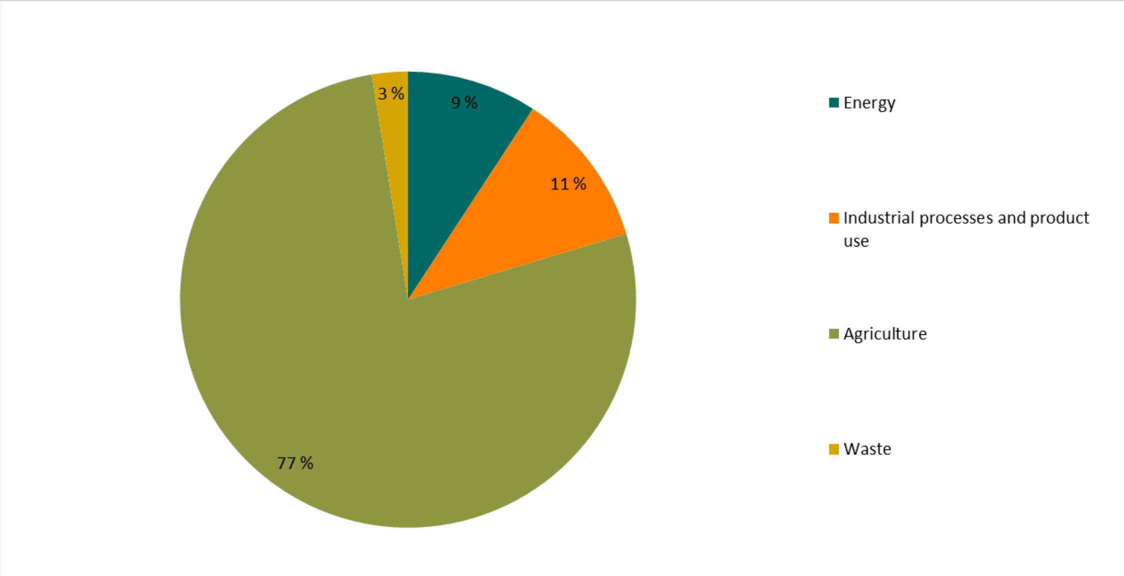


Figure 2.19: Distribution of Norwegian N_2O emissions by major sources in 2022. Source: Statistics Norway/Norwegian Environment Agency.

During the period 1990–2022 the total N_2O emissions decreased by 42%. From 2021 to 2022, the emissions decreased by 0.4%. 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_2O decomposition by extension of the reactor chamber.

Table 2-11: Emissions of N_2O (ktonnes) in Norway, 1990-2022.

Years	Energy	Industrial processes and product use	Agriculture	Waste	Total without LULUCF
1990	0.6	7.0	6.7	0.1	14.4
1995	0.7	5.7	6.6	0.2	13.0
2000	0.7	6.0	6.5	0.2	13.4
2005	0.6	6.8	6.6	0.2	14.2
2010	0.7	1.8	6.0	0.2	8.7
2011	0.7	1.6	6.2	0.2	8.8
2012	0.7	1.6	6.2	0.3	8.8

2013	0.7	1.4	6.3	0.3	8.7
2014	0.7	1.3	6.5	0.2	8.8
2015	0.7	1.4	6.6	0.2	8.9
2016	0.7	1.1	6.6	0.3	8.7
2017	0.7	1.0	6.4	0.2	8.4
2018	0.8	1.0	6.4	0.2	8.4
2019	0.8	0.9	6.6	0.2	8.5
2020	0.7	0.8	6.6	0.2	8.4
2021	0.8	0.7	6.7	0.2	8.4
2022	0.8	0.9	6.4	0.2	8.3

Source: Statistics Norway/Norwegian Environment Agency

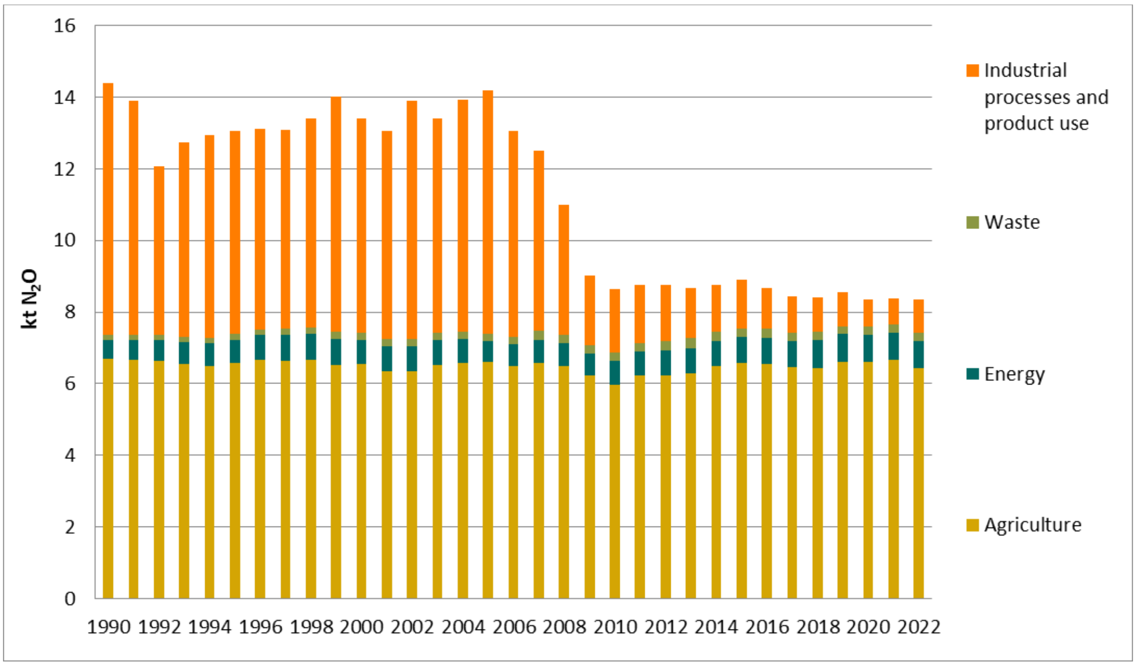


Figure 2.20: N_2O emissions in Norway, 1990-2022, without LULUCF. Source: Statistics Norway/Norwegian Environment Agency.

2.2.2.4 Perfluorcarbons (PFCs)

Aluminium production is the only source of PFC emissions in 2022. In 2022, the emissions of the perfluorcarbons tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) from Norwegian aluminium plants were reported at 16 tonnes and 1.7 tonnes respectively, corresponding to a total of 0.12 million tonnes of CO_2 equivalents. There were minor emissions of octafluoropropane (C_3F_8) from refrigeration in 2010-2014.

Total PFCs emissions have decreased by 97% since 1990 following a steady downward trend as illustrated in Figure 2.21. Since 1990, emissions of CF_4 decreased by 97%, while the emission of C_2F_6 have gone down by 95%.

Improvement of technology and process control in aluminium production led to a significant reduction in emissions. The PFC emissions per tonne aluminium produced in Norway was 4.02 kg CO_2 equivalents in 1990 and 0.09 kg CO_2 equivalents in 2022. Total PFCs emissions decreased by 0.1 million tonnes of CO_2 equivalents between 2021 and 2022.

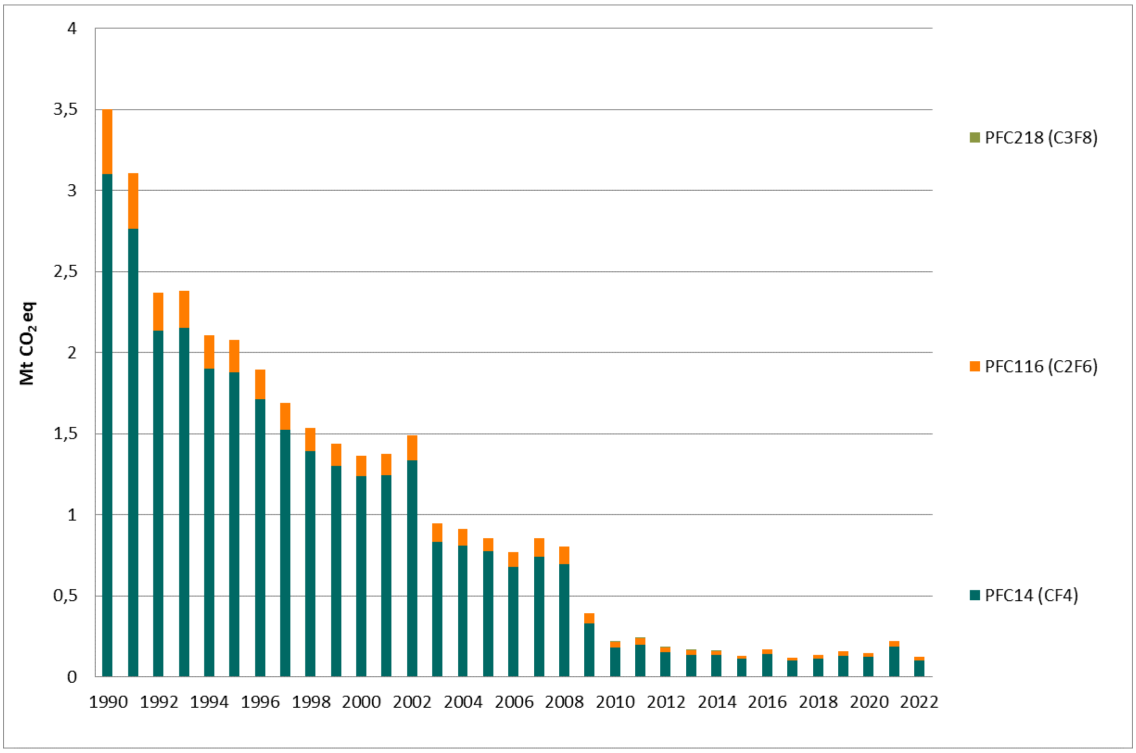


Figure 2.21: Emissions (million tonnes CO_2 eq) of PFCs in Norway, 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

Table 2-12: Emissions of PFCs in Norway in 1990-2022. Individual PFCs in tonnes, and totals in million tonnes of CO_2 eq.

Year	PFC14 (CF4) (t)	PFC116 (C2F6) (t)	PFC218 (C3F8) (t)	Total CO_2 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	0.0014	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
2022	15.5	1.7	-	0.1

Source: Statistics Norway/Norwegian Environment Agency

2.2.2.5 Sulphur hexafluoride (SF_6)

In 2022, the SF_6 emissions were 97% lower than in 1990. Until 2006, the largest source of SF_6 emissions in Norway was magnesium production. The consumption of SF_6 was reduced through the 1990s due to improvements in technology and process management, and to reductions in production levels. Until 2002, SF_6 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.

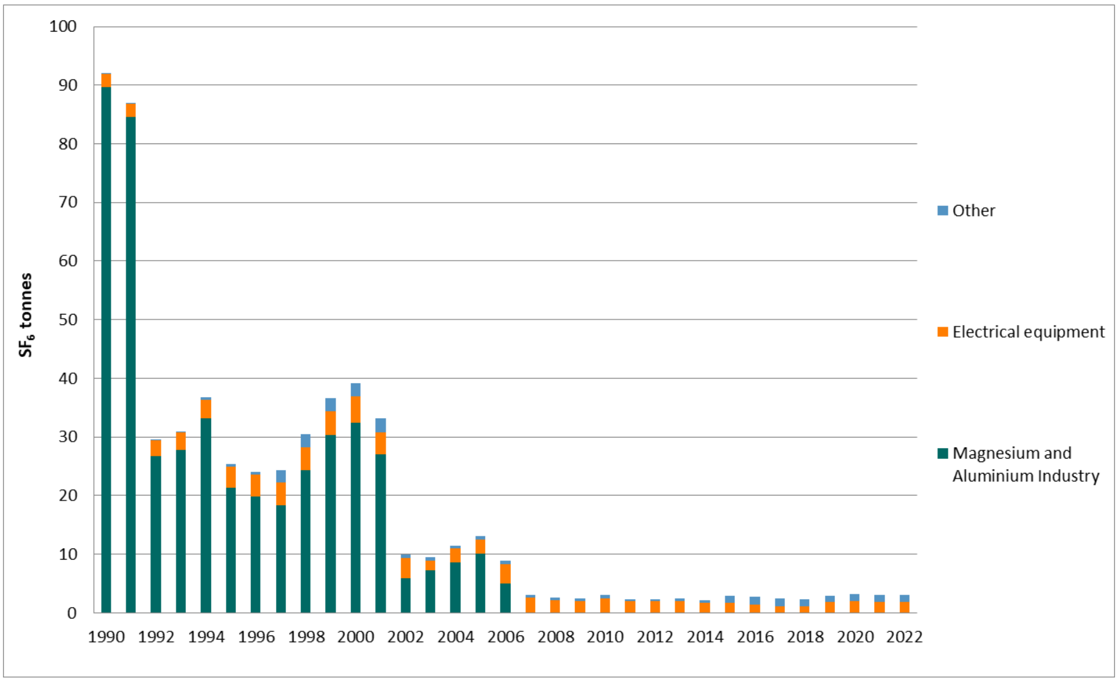
The main other use of SF_6 is in gas insulated switchgears (GIS) and other high-voltage applications. In 2002, a voluntary agreement was signed between the government and the business organisations representing most users of gas-insulated switchgear (GIS) as well as the single producer nationally. The 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 2-13: SF_6 emissions (tonnes), in Norway 1990-2022.

Year	Electrical equipment (t)	Magnesium and Aluminium Industry (t)	Other (t)	Total (t)
1990	2.2	89.7	0.1	92.0
1995	3.7	21.3	0.5	25.4
2000	4.5	32.4	2.2	39.1
2005	2.4	10.0	0.6	13.0
2010	2.5	-	0.5	3.0
2011	2.0	-	0.4	2.3
2012	1.9	-	0.4	2.3
2013	2.1	-	0.4	2.4
2014	1.8	-	0.4	2.1
2015	1.7	-	1.2	3.0
2016	1.5	-	1.2	2.7
2017	1.0	-	1.4	2.5
2018	1.2	-	1.2	2.3
2019	1.8	-	1.2	3.0
2020	2.1	-	1.2	3.2
2021	1.9	-	1.2	3.1
2022	1.9	-	1.2	3.0

Source: Statistics Norway/Norwegian Environment Agency



2.22: Emissions of SF_6 (tonnes) in Norway 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

2.2.2.6 Hydrofluorcarbons (HFCs)

The total emissions from HFCs used as substitutes for ozone depleting substances amounted to 0.7 million tonnes of CO_2 equivalents in 2022. The emissions in 1990 were insignificant (49 tonnes CO_2 equivalents) but have increased substantially over the years. The emissions increased by 0.5% from 2021 to 2022. This increase was mainly caused by a 10% increase in emissions from 2.F.1.a Commercial refrigeration. The increase was almost offset by a 4% decline in emissions from 2.F.1.e Mobile air-conditioning. 2.F.1.c, Industrial refrigeration, experienced a rapid decline of 44% between 2018 and 2020, and remained at a low level in 2022, constituting only 5% of the total HFC emissions in 2022, down from 10% 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 category other applications contributes to relatively small amounts to the overall emissions.

Table 2-14: Emissions of different specific HFCs (tonnes), unspecified mix of HFCs (Mtonnes CO_2 eq.) and total (Mtonnes CO_2 eq.) in Norway, 1990-2022.

Year	HFC23 (t)	HFC32 (t)	HFC125 (t)	HFC134a (t)	HFC143a (t)	HFC152a (t)
1990	-	-	-	-	-	0.36
1995	0.00	-	5.53	40.43	4.12	1.30
2000	0.06	0.73	34.56	68.75	29.06	1.79
2005	0.09	4.40	45.84	120.73	38.05	1.17
2010	0.05	17.52	66.22	224.75	44.40	0.94
2011	0.06	20.85	69.62	243.06	45.70	0.92
2012	0.07	23.33	72.51	263.37	45.13	0.77
2013	0.40	26.34	77.57	276.06	49.14	2.22
2014	0.36	27.80	75.61	290.42	44.63	1.13
2015	0.28	30.17	74.28	288.38	39.43	0.91
2016	0.25	31.39	72.86	303.20	36.16	0.97
2017	0.46	34.45	72.64	298.03	35.69	0.55
2018	0.19	35.73	74.44	287.69	33.16	0.55
2019	0.15	40.02	76.01	285.78	32.44	1.28
2020	0.14	42.66	69.62	270.97	26.36	0.82
2021	0.21	45.82	64.75	278.81	23.02	1.00
2022	0.20	51.75	65.27	274.72	24.26	0.72
Year	**HFC227ea (t)**	**HFC134 (t)**	**HFC143 (t)**	**Unspecified mix of HFCs (Mtonnes CO_2 eq.)**	**Total (Mtonnes CO_2 eq.)**	
1990	-	-	-	0.00	0.00	
1995	-	-	-	0.00	0.09	
2000	-	-	-	0.02	0.36	
2005	-	0.57	0.65	0.03	0.52	
2010	-	0.96	0.61	0.03	0.76	
2011	-	0.94	0.59	0.05	0.82	
2012	0.14	1.00	0.56	0.06	0.87	
2013	0.17	0.97	0.54	0.06	0.93	
2014	0.18	0.92	0.52	0.06	0.91	
2015	0.21	0.89	0.50	0.05	0.87	
2016	0.17	3.64	0.48	0.05	0.88	
2017	0.15	0.71	3.20	0.07	0.89	
2018	0.10	0.67	2.85	0.04	0.83	
2019	0.10	0.66	0.22	0.03	0.83	
2020	0.09	4.98	0.21	0.04	0.78	
2021	0.16	0.45	0.20	0.03	0.74	

2022	0.05	0.40	0.19	0.03	0.75	

Source: Statistics Norway/Norwegian Environment Agency

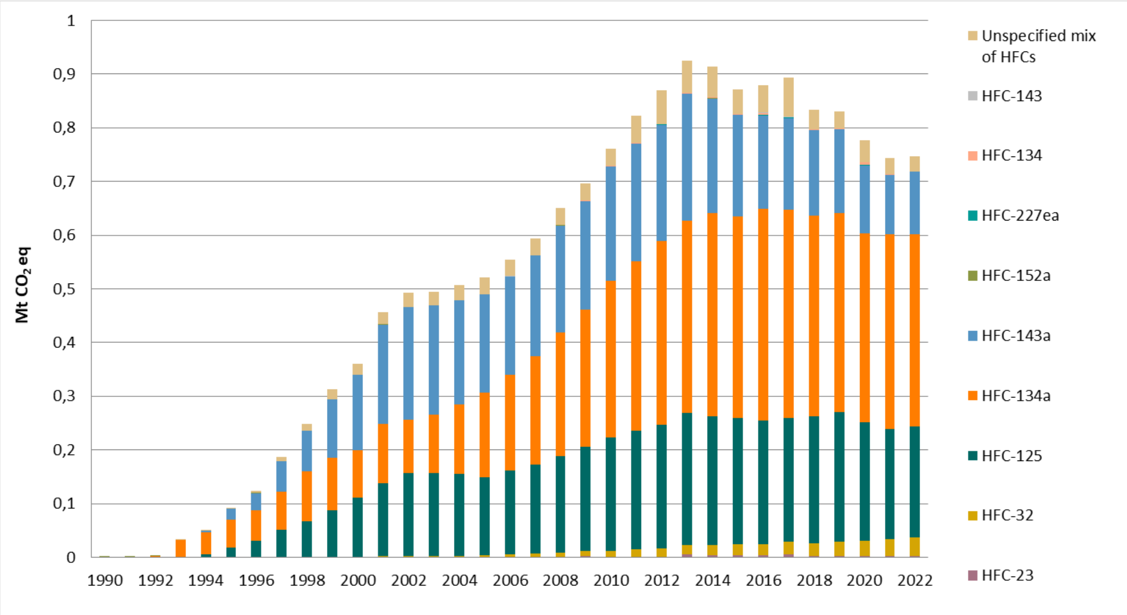


Figure 2.23: Emissions of HFCs (Mtonnes CO_2 eq.) in Norway, 1990-2022. Source: Statistics Norway/Norwegian Environment Agency.

2.2.3 Emission trends for indirect greenhouse gases and SO_2

Nitrogen oxides (NO_x), 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_2) 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_x emissions decreased with approximately 32% from 1990 to 2022. This can primarily be explained by stricter emission regulations for road traffic, which has led to a 64% and 47% reduction of NO_x emissions from road transport and overall transport, respectively, since 1990. These reductions counteracted increasing emissions from e.g., oil and gas production. From 2021 to 2022, the total NO_x emissions decreased by 5.2%.

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 66% from 2001 to 2022 and were in 2022, 55% 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 2021 to 2022, the emissions of NMVOC decreased by 5.9%.

CO emissions have decreased by 47% over the period 1990-2022. This is explained primarily by the implementation of new emission standards for motor vehicles.

SO_2 emissions were reduced by 71% from 1990 to 2022. 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.

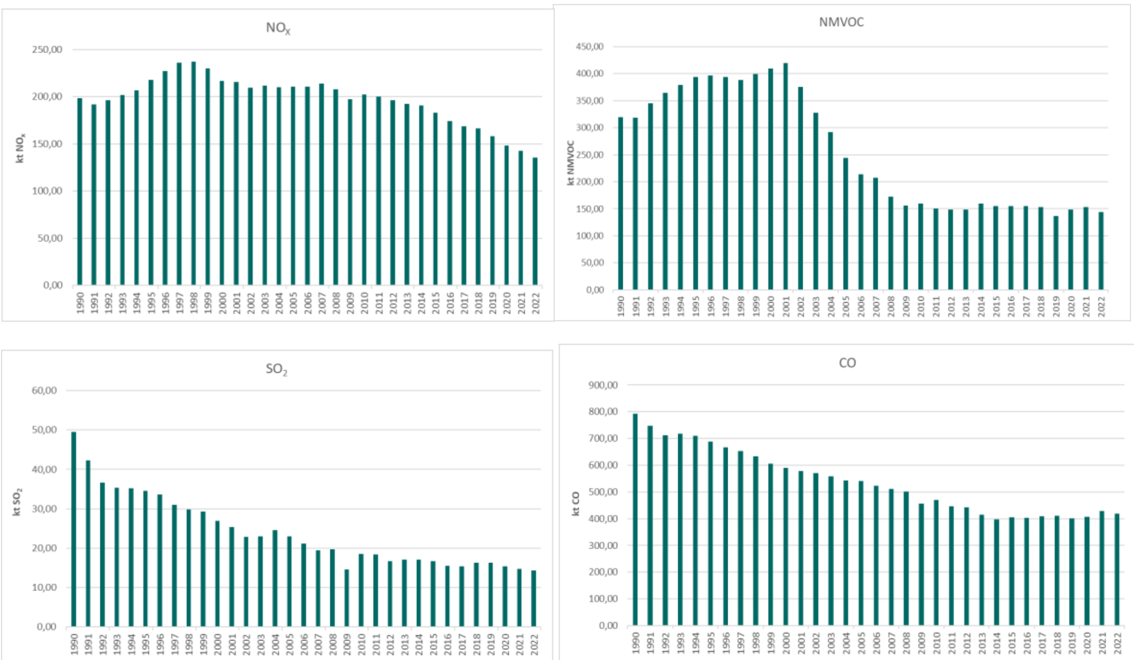


Figure 2.24: Emissions (ktonnes) of NO_x, NMVOC, SO_2, and CO in Norway, 1990-2022. Source: Statistics Norway/ Norwegian Environment Agency

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3. Energy (CRF sector 1)

3.1 Overview of the sector

3.1.1 Sources and trends

The Energy sector, including fugitive emissions, accounted for nearly 70% of the Norwegian greenhouse gas emissions in 2022. In 1990, the Energy sector's share of the total greenhouse gas emissions was 56%.

Road traffic and offshore gas turbines (electricity generation and pumping of natural gas in pipelines) are the 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 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 18% from 1990 to 2022 (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% higher than in 1990.

Since 2010, emissions have decreased by 15%. The reduction is mainly due to reduced emissions from oil and gas extraction, including flaring, and transport, particularly road transport. In 2022 emissions continued to sightly decrease. This was despite the reopening of an LNG plant which had been out of operation in 2021, and in 2022 emitted approx. 700 kilotonnes of GHG.

Temporarily reduced activity at an oil refinery reduced fugitive emissions in 2019 and 2020. The covid-19 pandemic contributed to reduced emissions in both 2020 and 2021, mainly in air and road transport. Emissions from these sources rebounded between 2021 and 2022.

Total sales of gasoline and auto diesel including biofuels reached a peak in 2016 and has since decreased by 11% 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 12 and 15% of total road fuels by volume. The biofuel fraction in 2022 was 13%.

Figure 1.1 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[11] and the fugitive emissions from fuel sector have all decreased between 1990 and 2022.

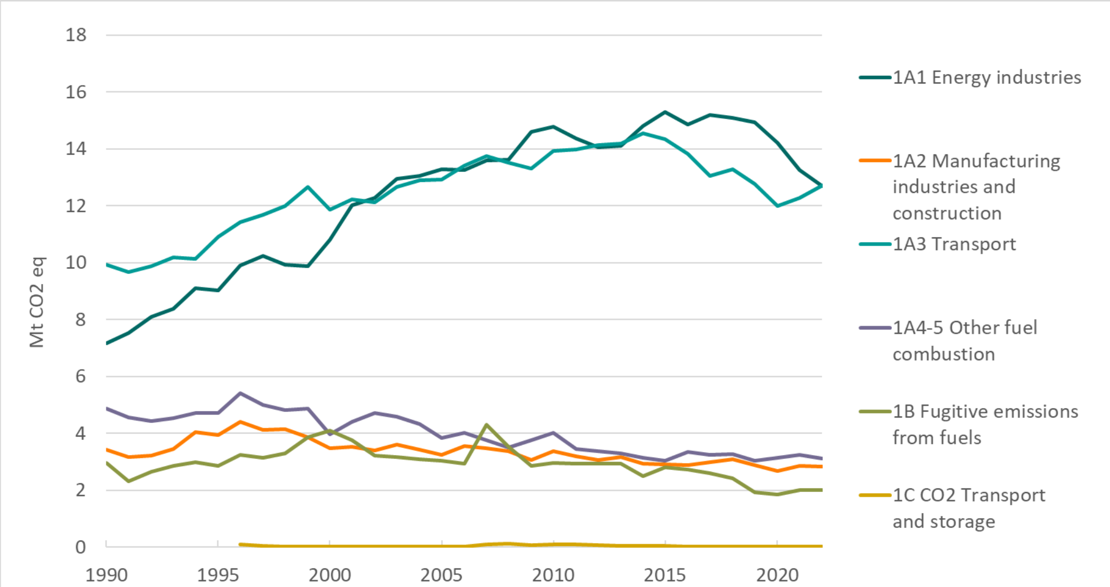


Figure 3.1: Greenhouse gas emissions from energy sectors and fugitive emissions. Million tonne CO_2 equivalents. Source: Statistics Norway/Norwegian Environment Agency.

[11] "Other fuel combustion sector" includes both the sectors Other Combustion (CRF 1A4) and Other (CRF 1A5)

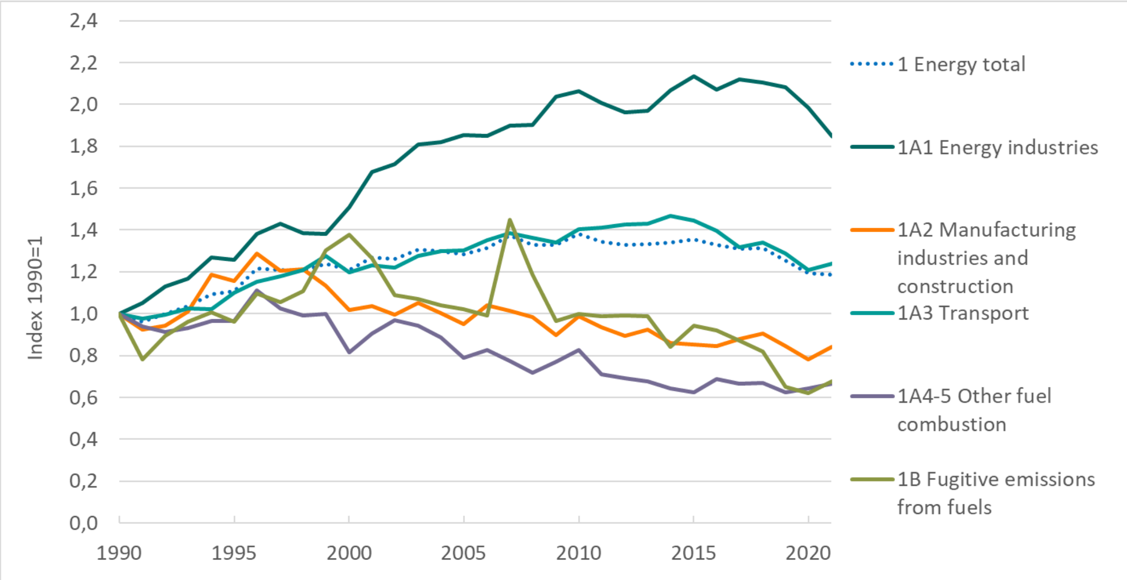


Figure 3.2: Relative changes to 1990 in GHG emissions for energy combustion. Index 1990=1. Source: Statistics Norway/Norwegian Environment Agency.

Figure 3.3 and Figure 3.4 show the trend and the relative changes of transport emissions from 1990 to 2022. In 2022, the total GHG emissions in the transport sector was 12.7 million tonnes CO_2 equivalents, of which road transportation contributed to 68%, navigation to 23%, civil aviation to 8% and railways to less than 1%.

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 53%, navigation by 74% and road transportation by 17%. Emissions from road transport have decreased significantly since 2015, mainly due to use of biofuels and increased use of electric vehicles. Emissions from railways have decreased by 47% compared with 1990. Emissions from road traffic and in particular aviation dropped sharply in 2020 due to the covid-19 pandemic but has since rebounded.

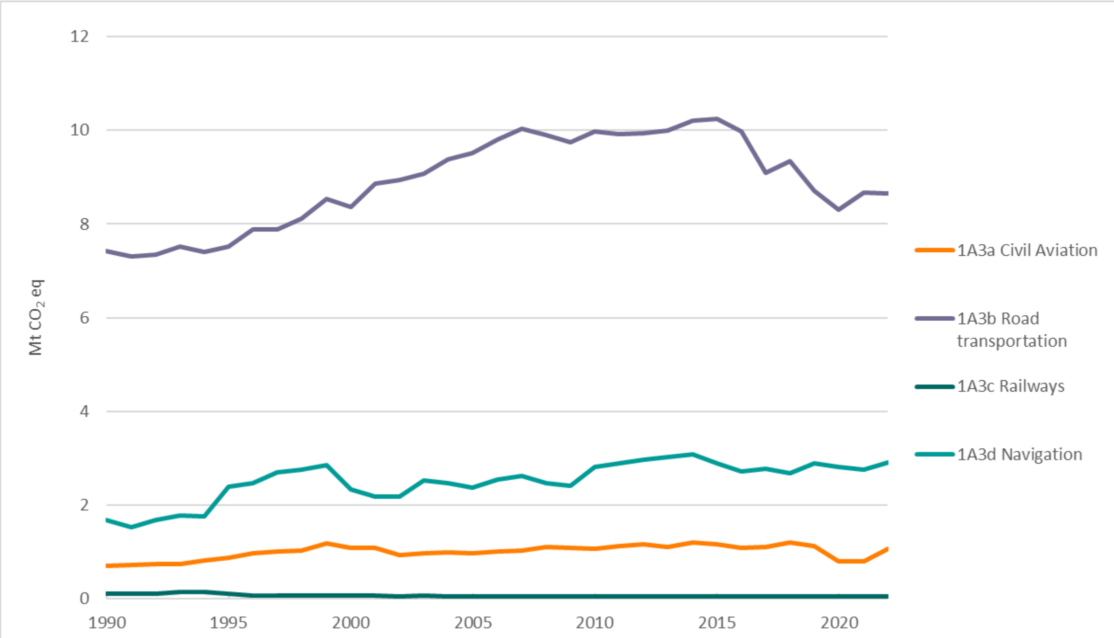


Figure 3.3: Greenhouse gas emissions from the most important transport sectors. Million tonnes CO_2 equivalents. Source: Statistics Norway/ Norwegian Environment Agency.

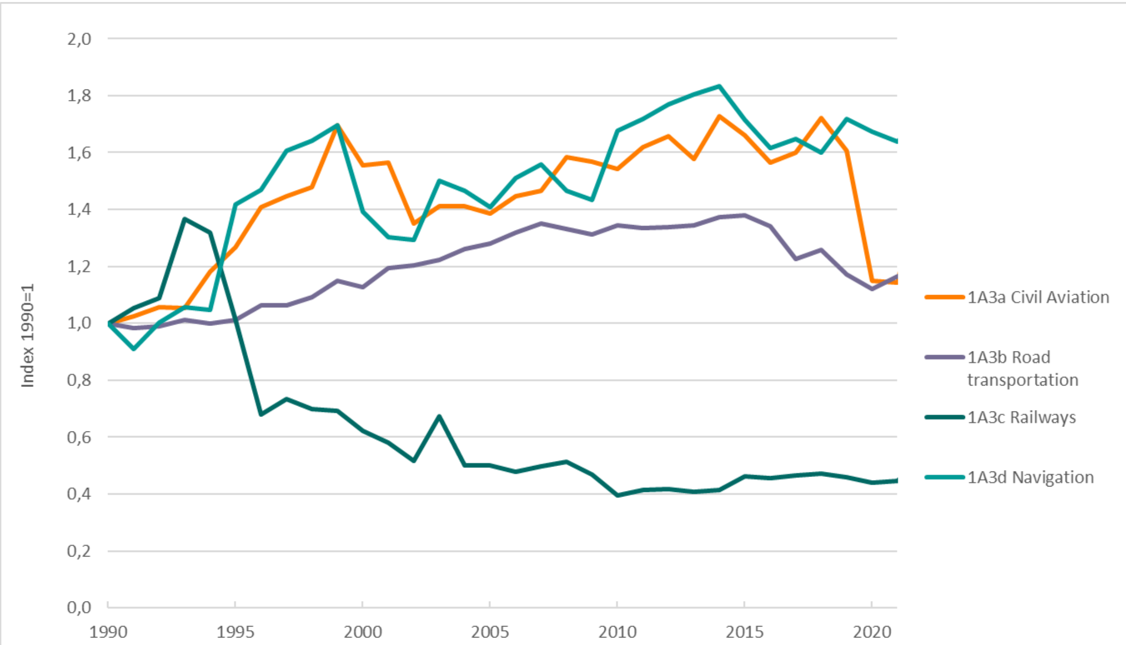


Figure 3.4: Relative changes to 1990 in GHG emissions for the most important transport sectors. Civil aviation, road transportation, navigation, and other transportation. Index 1990=1.

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 2022. 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.

Table 3-1: Key categories in the Energy sector.

CRF code	Source Category	Gas	Method
1A1, 1A2, 1A4	Fuel Combustion Activities (Sectoral Approach) Biomass	CH_4	Tier 2
	Fuel Combustion Activities (Sectoral Approach) Gaseous Fuels	CO_2	Tier 2
	Fuel Combustion Activities (Sectoral Approach) Liquid Fuels	CO_2	Tier 2
	Fuel Combustion Activities (Sectoral Approach) Other Fuels	CO_2	Tier 2
	Fuel Combustion Activities (Sectoral Approach) Solid Fuels	CO_2	Tier 2
1A3A	Civil Aviation	CO_2	Tier 2
1A3B	Road Transportation	CO_2	Tier 2
		CH_4	Tier 2
		N2O	Tier 2
1A3D	Navigation	CO_2	Tier 2
		CH_4	Tier 2
1A4	Other sectors	CO_2	Tier 2
1A5B	Mobile	CO_2	Tier 2
1B1A	Coal Mining	CH_4	Tier 1
1B2A	Oil (incl. oil refineries, gasoline distribution)	CO_2	Tier 2
		CH_4	Tier 2
1B2C	Venting and Flaring	CO_2	Tier 2
		CH_4	Tier 2

An important issue, which is also elaborated in this sector, concerns the capture, transport, and storage of CO_2 from natural gas produced at the gas-condensate field Sleipner Vest, including gas from the Gudrun field, and the gas field Snøhvit. 1C is therefore qualitatively identified as a key category for CO_2. These unique operations are discussed in detail in section 3.4. The emissions are quantified using tier 3 methods.

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 the share of waste incinerated with utilization of the energy at district heating plants are accounted for under the energy sector. 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 3.3, as this energy combustion is not for energy purposes. Emissions from burn off of coke as 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, emissions 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 (section 3.3) and a discussion on the capture, transport, and storage of CO_2 from natural gas produced at the gas-condensate field Sleipner Vest, including gas from the Gudrun field, and the gas field Snøhvit (section 3.4).

A comparison between the sectoral and reference approach is provided in section 3.2.1. The memo item of international bunker fuels is addressed in section 3.2.2. Feedstock and non-energy use of fuels is described in section 3.2.3.

Indirect CO_2 emissions from CH_4 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 (CRT 1.A)

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 64% of national total emissions in 2022, and more than 90% of the total emissions from the energy sector. The emissions increased by 24% between 1990 and 2022. The increase is primarily due to activity growth in oil and gas extraction, which comprises the greater part of the energy industries sector, and in transport, mainly road transport.

The fuel combustion sector is dominated by emissions of CO_2, which in 2022 contributed 98% 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 1-1).

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 2022. 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.

Mandatory reporting obligation 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. As part of the agreements, industry has every year reported detailed activity data and emissions to the Norwegian Environment Agency. The voluntary agreements have involved industry i.e., ferroalloy, aluminium, ammonia. Since 2013 most of these industries are also part of the ETS.

Annex 5a 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.

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 shown in equation 1. Exceptions are road traffic and aviation, where more detailed estimation models are used; involving additional activity data (see sections 3.2.7 and 3.2.6, respectively). The total amounts of fuel consumption are taken from the Norwegian energy balance[12].

The mean theoretical energy contents of fuels and their densities 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.

Table 3-2: Average energy content (Net calorific value, NCV) and density of fuels.*

Energy product	Theoretical energy	Unit	Density	Unit
Coal	28.1	GJ/tonne	:	:
Coke	28.5	GJ/tonne	:	:
Petrol coke	35	GJ/tonne	:	:
Crude oil	42.7	GJ/tonne	0.85	tonne/m^3
Motor gasoline	43.9	GJ/tonne	0.74	tonne/m^3
Aviation gasoline	43.9	GJ/tonne	0.74	tonne/m^3
Kerosene (heating)	43.1	GJ/tonne	0.81	tonne/m^3
Jet kerosene	43.1	GJ/tonne	0.81	tonne/m^3
Diesel	43.1	GJ/tonne	0.84	tonne/m^3
Marine gas oil/diesel	43.1	GJ/tonne	0.84	tonne/m^3
Light fuel oils	43.1	GJ/tonne	0.84	tonne/m^3
Heavy distillate	43.1	GJ/tonne	0.88	tonne/m^3
Heavy fuel oil	40.6	GJ/tonne	0.98	tonne/m^3
Bitumen	40.2	GJ/tonne	1.1	tonne/m^3
Lubricants	40.2	GJ/tonne	0.9	tonne/m^3
Natural gas (dry gas) (land)[1]	35.3	GJ/1000 Sm^3	0.741	tonne/kSm^3
Natural gas (rich gas) (offshore)[1]	40.3	GJ/1000 Sm^3	0.851	tonne/kSm^3
LPG	46.1	GJ/tonne	0.53	tonne/m^3
Refinery gas	47.3	GJ/tonne	:	:
Blast furnace gas[1]	7.5-11	GJ/1000 Sm^3	0.0012	ktonn/kSm^3
Fuel gas[3]	60	GJ/tonne	:	:
Landfill gas[2,4]	50.4	GJ/tonne	0.717	tonne/kNm^3
Biogas[2,4]	50.4	GJ/tonne	0.593	tonne/kSm^3
Fuel wood[2]	16.8	GJ/tonne	0.5	tonne/fm^3
Ethanol[2]	26.8	GJ/tonne	0.79	tonne/m^3

[12] 11561: Energy balance. Supply and consumption, by energy product 1990 - 2022. Statbank Norway (ssb.no)

Biodiesel[2]	36.8	GJ/tonne	0.88	tonne/m[3]
Wood waste[2]	16.8	GJ/tonne	0.4	tonne/fm[3]
Black liquor[2]	7.2 - 9.2	GJ/tonne	:	:
Wood pellets[2]	17.3	GJ/tonne	:	:
Municipal waste	11.5	GJ/tonne	:	:
Special waste	40.6	GJ/tonne	0.98	tonne/m[3]

Source: Statistics Norway/Norwegian Environment Agency

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

[1]*kg/Sm[3]. Sm[3] = standard cubic meter (at 15 °C and 1 atmospheric pressure).*

[2] *Non-fossil emissions, not included in the inventory* CO_2 *totals. Value is given for wood including a water content of 18%, wood waste 8%, and pellets 8%. Values for black liquor are given not including water content.*

[3] *In this inventory, fuel gas is a hydrogen-rich excess gas from petrochemical industry.*

[4] *Landfill gas and other types of biogases are reported as methane content in the energy balance*

The general method for calculating emissions from energy consumption is:

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

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:

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

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 1.3.1 for more information about the main emission model.

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 2. 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. This means that the figures for these compounds will be a mixture of reported and estimated emissions.

Emissions are reported to the Norwegian Environment Agency under several different reporting obligations. Most of the CO_2 emissions are reported as part of the Emissions Trading System (ETS).

In the general equation 1, E_{PS} represents the reported emission data, while A_{PS} 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_2, CH_4 and N_2O in 2022.

In 2022, 91% of the CO_2 emissions from Energy Industries and 22% of the CO_2 emissions from Manufacturing Industries and Construction were based on reported emissions.

Table 3-3: Share of total CO_2, CH_4 and N2O emissions in the energy sector based on estimated and reported emission estimates for 2022.

	CO2		CH4		N2O	
	Estimated	Reported	Estimated	Reported	Estimated	Reported
A. Fuel Combustion Activities (Sectoral Approach)	60%	40%	92%	8%	96%	4%
1. Energy Industries	9%	91%	37%	63%	78%	22%
a. Public Electricity and Heat Production	81%	19%	99%	1%	70%	30%
b. Petroleum Refining	0%	100%	4%	96%	100%	0%
c. Manufacture of Solid Fuels and Other Energy Industries	0%	100%	0%	100%	100%	0%
2. Manufacturing Industries and Construction	78%	22%	100%	0%	98%	2%
a. Iron and Steel	8%	92%	100%	0%	100%	0%
b. Non-Ferrous Metals	100%	0%	100%	0%	100%	0%
c. Chemicals	64%	36%	98%	2%	73%	27%
d. Pulp, Paper and Print	100%	0%	100%	0%	100%	0%
e. Food Processing, Beverages and Tobacco	100%	0%	100%	0%	100%	0%
f. Non-metallic minerals	28%	72%	100%	0%	100%	0%
g. Other (Oil drilling, construction, other manufacturing)	100%	0%	100%	0%	100%	0%
3. Transport	100%		100%		100%	
a. Civil Aviation	100%		100%		100%	
b. Road Transportation	100%		100%		100%	
c. Railways	100%		100%		100%	
d. Navigation	100%		100%		100%	

e. Other Transportation (pipeline transport)	(IE)	(IE)	(IE)
4. Other Sectors	100%	100%	100%
a. Commercial/Institutional	100%	100%	100%
b. Residential	100%	100%	100%
c. Agriculture/Forestry/ Fisheries	100%	100%	100%
5. Other (Military)	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 3.1.3.

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_2 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_2 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_2 from combustion at petrochemical and ammonia plants is reported under industrial processes (CRF 2B). CO_2 from coke that is burnt off from catalytic crackers in refineries is reported under fugitive emissions (CRF 1B). This also applies to CO_2 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_2 emissions. This gives meaningful implied emission factors for CO_2, while IEFs for other substances may be skewed.

At a small number of plants in the chemical industry, CO_2 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 2D).

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 (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_4 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):

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

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_2 emissions from natural gas in almost all activities
- CO_2 emissions from cement production, 2008 and later
- CO_2 emissions from iron and steel production, 2008 and later
- CO_2 and several other substances from oil and gas production, offshore and onshore

Except for the cases listed above, fuel specific CO_2 emissions from the emission trading system reports (ETS) are not entered into the inventory, only the total plant emission is used.

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 oil and gas activities and energy-intensive industries onshore. 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 (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.

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. The energy balance for all years in the reporting period are published in Statistics Norway's Statbank[13].

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 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 data source for the amounts of gas combusted, distributed between gas turbines and flaring, is Footprint in addition to the Norwegian Offshore Directorate. 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_2 from the largest gas consumers, e.g., offshore activities, gas terminals, and petrochemical industry, are figures reported by the plants. The data are of high quality, due to the Norwegian system of CO_2 taxation on fuel combustion.

[13] 11561: Energy balance. Supply and consumption, by energy product 1990 - 2022. Statbank Norway (ssb.no)

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. In addition, Statistics Norway’s District heating statistics gives data for natural gas and other fuels used in production of district heating. Some natural gas is also used for auto producer electricity production. This is mainly calculated on basis of the plant’s electricity production. In cases where for instance gas terminals produced their own electricity, the estimated gas used for electricity production is deducted from their total gas consumption (reported by Gassco or the Norwegian Offshore Directorate).

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[14]. Figures on use of LPG in households, services and construction are based on sales figures, collected annually from the oil companies. Use in agriculture is taken from agriculture statistics (Gundersen 2005) prior to 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. 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 3.3 (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.

[14] https://www.ssb.no/en/energi-og-industri/statistikker/indenergi

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". In international reporting however, this is reported as petroleum coke used as refinery fuels.

Liquid fuels: Oil products

The total use of the different oil products is based on Statistics Norway's annual sales statistics for petroleum products[15]. 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 used for combustion. The use in the different sectors must sum up to this total. This is not the case for the other energy carriers, except for instance for blast furnace gas and refinery gas, where we collect already balanced figures for production and consumption from the same respondents. 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.

[15] https://www.ssb.no/en/energi-og-industri/statistikker/petroleumsalg/aar

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 3.2.6 to 3.2.11).

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.

Petroleum 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% 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. In addition, there is a small amount of coal used in a few veteran trains in Norway. This is considered as consumption in cultural services and are not a part of the transport sector. This figure is assumed to be on about the same every year and is not collected annually.

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, 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 products 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 centre 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*.13* shows the consumption of biofuels in the transport sector. The amounts 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_2 emissions. Other emissions are estimated by Statistics Norway, using the same emission factors as for combustion of natural gas in turbines.

<u>Other fossil fuels: Waste and waste oil</u>
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_2, NO_X, CO, NH_3, particles, heavy metals and dioxins, and the amount of waste incinerated 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.

Data on the use of waste oil are given in Statistics Norway's statistics on energy use in the manufacturing industries. Statistics Norway also collects additional information directly from a few companies on the use of waste oil as a fuel source. Activity data for waste oil are reported together with waste in the category "other fossil fuels".

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 for Norway is published in Statistics Norway's Statbank[16].

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. The main consequence of this is that energy used by Norwegian transport trades and tourists abroad is 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.

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.

An important difference between figures presented in the energy balance sheet (EBS) and figures used in the emission calculations is that 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 emission calculations include only energy used for combustion in the calculation of emissions from energy.

[16] 11561: Energy balance. Supply and consumption, by energy product 1990 - 2022. Statbank Norway (ssb.no). https://www.ssb.no/en/statbank/table/11561

Emission factors

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

CO2

Emission factors for CO_2 are independent of technology and are based on the average carbon content of fuels used in Norway. The general emission factors for CO_2 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^3 fuel are the ones that are used in the inventory.

Table 3-4: General emission factors for CO_2.

Energy product	Emission factors	
	Tonne CO_2/tonne fuel	Tonne CO_2/TJ fuel
Coal	2.52	89.68
Coke	3.19	111.93
Petrol coke	3.59	102.57
Crude oil	3.2	75.65
Motor gasoline	3.13	71.3
Aviation gasoline	3.13	71.3
Kerosene (heating)	3.15	73.09
Jet kerosene	3.15	73.09
Diesel	3.17	73.55
Marine gas oil/diesel	3.17	73.55
Light fuel oils	3.17	73.55
Heavy distillate	3.17	73.55
Heavy fuel oil	3.2	78.82
Natural gas (dry gas) (kg/Sm^3) (land)	1.99	56.08
Natural gas (rich gas) (kg/Sm^3) (offshore)[1]	2.34	58.09
LPG	3	65.08
Refinery gas	2.8	57.61
Blast furnace gas	1.571	198
Fuel gas[3]	3.0	50
Landfill gas[2,4]	2.75	54.56

Biogas[2,4]	2.75	54.56
Fuel wood[2]	1.8	107.14
Ethanol[2]	1.91	71.27
Biodiesel[2]	2.85	77.45
Wood waste[2]	1.8	100-110.77
Black liquor[2]	1.8	195.65-250
Charcoal	3.299	111.83
Municipal waste	0.592	51.478
Special waste	3.2	78.82

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

[1]*The emission factor for natural gas used in the emission inventory varies as indicated in tables*
Table **3-5** *and*
Table **3-6**.

[2]*Non-fossil emissions, not included in the inventory* CO_2 *totals. Emission factor for wood includes water content.*

[3] *In this inventory, fuel gas is a hydrogen-rich excess gas from petrochemical industry.*

[4] *Landfill gas and other types of biogases are reported as methane content in the energy balance.*

[5] *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.*

CH4 and N2O

For CH_4 and N_2O, information on emission factors is generally very limited, because, unlike the CO_2 emission factors, they depend on the source of the emissions and the sector where the emissions take place. CH_4 and N_2O 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) and (Morten Seljeskog et al. 2017). 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_4 and N_2O 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.

Table 3-5: General emission factors for CH_4, stationary combustion. Unit: kg CH_4 / TJ.

Energy product	Direct-fired furnaces	Gas turbines	Boilers	Small stoves	Flares
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		7.3
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) Morten Seljeskog et al. (2017) and OLF (1994)
**Numbers have exceptions for some sectors, see*
Table **3-6**

Table 3-6: Exceptions from the general factors for CH_4, stationary combustion. Unit: kg CH_4/TJ.

Emission factor	Fuel	Source	Sectors
3	Kerosene (heating), marine diesel; light fuel oil, heavy distillate	Direct fired furnaces	Energy industry and manufacturing of product
3	Heavy fuel oil	Direct fired furnaces, boilers	Energy industry and manufacturing of product
1	LPG	Boilers	Energy industry and manufacturing of product
1.14	Natural gas	Direct fired furnaces, boilers	Extraction of oil and gas
1	Natural gas	Direct fired furnaces, boilers	Energy industry and manufacturing of product
0	Blast furnace gas	Boilers	Refinery
1	Landfill gas, Biogas	Gas turbines, boilers	Energy industry and manufacturing of product
30	Wood waste	Boilers	Energy industry and manufacturing of product
300	Wood briquettes	Boilers	Private households
959	Wood	Stoves (Pre-1998 technology)	Private households
228	Wood	Stoves (Post-1998 technology)	Private households
315	Wood	Open fireplaces	Private households

Source: IPCC (2006), SFT (1996), SINTEF (1995), (Morten Seljeskog et al. 2017) OLF (1994) . 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.

Table 3-7: General emission factors for N2O, stationary combustion. Unit: kg N2O/TJ.

Energy product	Direct-fired furnaces	Gas turbines	Boilers	Small stoves	Flares
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*

Table 3-8: Exceptions from the general factors for N2O, stationary combustion. Unit: kg N2O/TJ.

Emission factor	Fuel	Source	Sectors
0.11	Natural gas	Direct-fired furnaces, gas turbines, boilers	Extraction of oil and gas

Source: Statistics Norway

Uncertainties and time series consistency

Uncertainty estimates for greenhouse gases are presented and discussed in Annex 2, 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_2 tax and other taxes. The project undertaken for the RA/SA comparison also underlines that this statistic is reliable (See Norway's NIR 2023, annex XI). 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 (See Norway's NIR 2023, annex XI). 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.

<u>Category-specific QA/QC and verification</u>

Emission sources in the energy sector are subjected to the QA/QC procedures described in Section 1.5 and in Annex 5a QAQC 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 two internal documents from Statistics Norway (Skullerud 2014; Thovsen 2017).

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 Anually)). 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 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, since 2005, the Environment Agency also receives 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 was established from 1990. Thirdly, the Norwegian Environment Agency receives emission data through a voluntary agreement established in 1997 between the authority and several industrial agents. Since 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 by the Norwegian Environment Agency and Statistics Norway. See Annex 5a QAQC of point sources.

<u>Category-specific recalculations</u>
Most of the recalculations have been performed for the penultimate inventory year (2021) because some of the energy figures used in the previous inventory were preliminary. There will always be some changes in the energy figures for the penultimate year. 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.

<u>Category-specific planned improvements</u>

See chapter 10.4 for planned improvements relating to the review process. In addition, Norway plans improvements on biogas, coal production, wood burning, road traffic and leisure boating.

3.2.1 Comparison of the sectoral approach with the reference approach

This chapter describes the status of the RA/SA comparison. The chapter also includes a comparison of the RA supply data to data reported to the IEA/Eurostat.

3.2.1.1 Comparison of the Reference Approach with the Sectoral Approach

The difference between the fuel consumption in the RA and SA ranges from about –17 to + 51%. The differences for CO_2 emissions ranges between -15 and +57%. The highest discrepancy for CO_2 is in 1991, 1999-2001 and in 2004-2006. For 2022, the difference for fuel consumption is -16.9% and for CO_2 -14.9%.

The reference approach is 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.

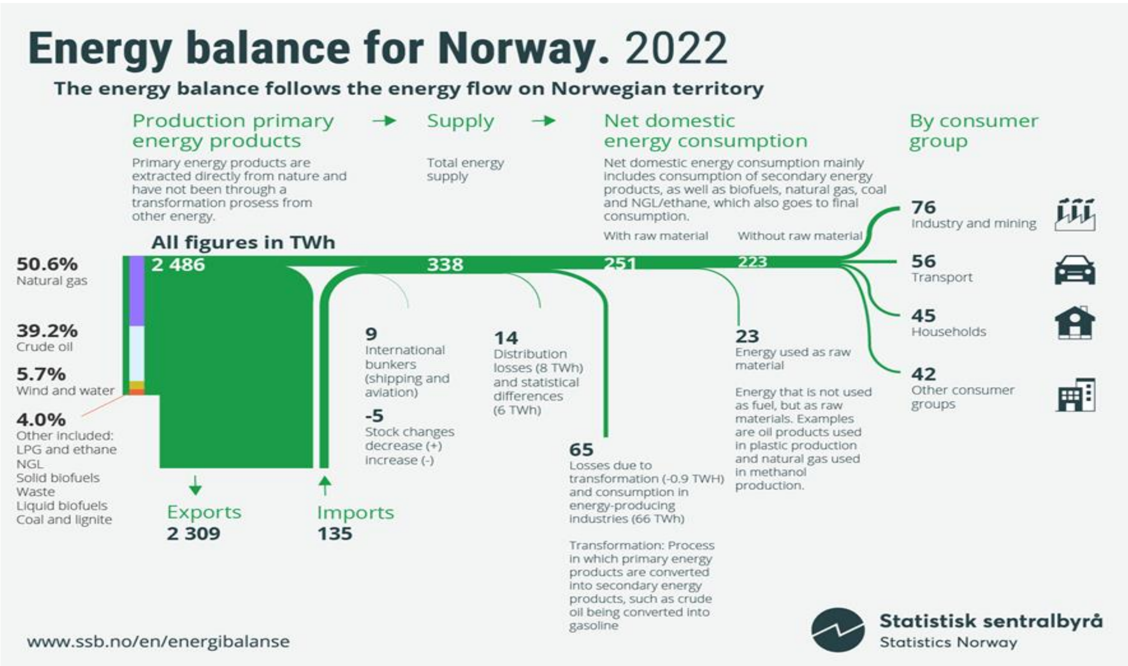


Figure 3.5: Energy balance for Norway.

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 2022 the production of primary energy products was 2 486 TWh. The export was 2 309 TWh, which means that more than 90% of the production was exported. The total energy supply was 338 TWh, which is less than 14% 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 3-9 below. The differences between RA and SA were largest in 2000, and for this year the statistical differences were almost 51% relative to the SA. Despite this, the statistical differences were not larger than 2.5% compared to total production of primary energy products. The statistical differences were -16,9% of SA in 2022, but less than -1% relative to total production. In order for the differences between RA and SA to be below 2% or 5% in 2022, the statistical differences would have to be no more than 0.11 or 0,3% 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%. 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 4% in any year, and for the last 10 years there are no differences that are more than 1%.

Table 3-9: Comparison of fuel consumption and CO_2 emission data between the Reference Approach1 (RA) and the Sectoral Approach (SA).

Year	Fuel consumption			CO_2 emissions		
	RA, apparent consumption (PJ)	SA (PJ)	Difference RA-SA (%)	RA, apparent consumption (PJ)	SA (PJ)	Difference RA-SA (%)
1990	342	358	-4.6	25 302	24 624	2.8
1995	412	408	1.1	29 097	27 770	4.8
2000	649	431	50.5	46 158	29 326	57.4
2005	621	479	29.8	43 551	32 566	33.7
2010	624	537	16.3	42 505	35 307	20.4
2011	493	518	-4.7	33 628	34 267	-1.9

2012	534	512	4.3	36 003	33 842	6.4
2013	576	522	10.4	39 383	34 047	15.7
2014	573	530	8.3	38 814	34 743	11.7
2015	575	531	8.2	38 935	34 899	11.6
2016	500	523	-4.3	33 156	34 249	-3.2
2017	579	517	12.1	39 519	33 799	16.9
2018	553	513	7.9	37 416	34 076	9.8
2019	491	499	-1.6	32 896	33 004	-0.3
2020	483	476	1.6	32 414	31 375	3.3
2021	456	469	-2.9	31 152	30 987	0.5
2022	385	464	-16.9	26 093	30 651	-14.9

Source: Statistics Norway/Norwegian Environment Agency
[1] Apparent energy consumption (excluding non-energy use, reductants, and feedstocks)

3.2.1.2 Comparison of the Reference Approach with international data

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. Energy supply data in the Reference Approach have been revised in the current 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 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 data from 2022.

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 3-10 shows 2022 energy supply data from the RA and Eurostat by fuel groups.

Table 3-10: Comparison of energy data in the CRF Reference Approach to data published by Eurostat. 2022.

	CRF Reference Approach, PJ					
	Prod.	Imp.	Exp.	Bun-kers	Stock change	App. cons.
Liquid	3 870	381	3 901	31	17	302
Solid	4	34	2	-	1	34
Gaseous	4 571	2	4 405	-	-	168
Other fossil	11	-	-	-	-	11
Total	8 457	418	8 309	31	18	517

	Eurostat, PJ					
	Prod.	Imp.	Exp.	Bun-kers	Stock change	App. cons.
Liquid	3 856	380	3 898	31	17	291
Solid	3	34	2	-	1	34
Gaseous	4 572	2	4 405	2	-	167
Other fossil	11	-	-	-	-	11
Total	8 442	417	8 306	32	18	503

	Difference, PJ					
	Prod.	Imp.	Exp.	Bun-kers	Stock change	App. cons.
Liquid	14.4	1.3	3.2	0.7	0.2	11.6
Solid	0.5	0.0	0.0	-	-0.0	0.5
Gaseous	0.0	0.0	-0.0	-1.6	-0.0	1.7
Other fossil	0.2	-	-	-	-	0.2
Total	15.1	1.3	3.2	-0.9	0.1	14.1

	Difference, % (base: Eurostat)					
	Prod.	Imp.	Exp.	Bun-kers	Stock change	App. cons.
Liquid	0.4	0.4	0.1	2.2	1.0	3.8
Solid	14.1	0.0	0.0	.	-0.0	1.6
Gaseous	0.0	0.0	-0.0	.	13.4	1.0
Other fossil	2.0	.	.	.	.	2.0
Total	0.2	0.3	0.0	-3.0	0.7	2.7

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 14.1 PJ or 2.7% higher in the RA than by Eurostat. The main reasons are NCV differences for NGL production and NGL/naphtha export, and data for refinery feedstocks. Some issues raised by the table:

- For *liquid* fuels, the main difference relates to production data for NGL. Production according to the RA was approximately 20 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.
- In addition, there were smaller differences in foreign trade data for several fuels, leading to larger apparent consumption in the RA.
- For *solid* fuels coal production is 0.5 PJ (16%) higher in the RA because production at Svalbard by Russian companies were included. This production is not included in the energy balance.
- For *gaseous fuels*, the main difference relates to international bunkers. The CRF does not allow data for bunkers of gaseous fuels. Thus, the RA apparent

consumption is 1.7 PJ too high, relative to both Eurostat and the published energy balance. Thus, the difference is -100%.

- 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 3a, table A3a-1, and the TJ data especially in

Table 3-10 were prepared using these values.

3.2.2 International bunker fuels

3.2.2.1 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 3-11.

In 2022 CO_2 emissions from ships and aircraft in international traffic bunkered in Norway amounted to a total of 2.4 million tonnes, which corresponds to 5% of the total Norwegian CO_2 emissions.

The CO_2 emissions from international navigation bunkered in Norway in 2022 was 1.0 million tonnes. During the period 1990-2022, emissions of CO_2 from marine bunkers decreased by 55%. The emissions reached a peak in 1997. Thereafter there has been a descending trend in emissions.

The CO_2 emissions from international air traffic bunkered in Norway in 2022 was 1.4 million tonnes. The emissions in 2022 were 110% higher than in 1990 due to a higher activity level and 164% higher than 2021 due to the covid-19 pandemic.

Table 3-11: Emissions from ships and aircraft in international traffic bunkered in Norway. 1000 tonne.

	Aviation			Marine		
	CO_2	CO_2	N_2O	CO_2	CO_2	N_2O
1990	643	0.008	0.039	2302	0.166	0.328
1995	563	0.006	0.034	2294	0.166	0.326
2000	886	0.009	0.054	2831	0.205	0.409
2005	910	0.008	0.055	2597	0.188	0.365
2010	1289	0.01	0.078	1682	0.122	0.219
2015	1623	0.012	0.102	1102	1.400	0.124
2016	1587	0.012	0.099	899	1.867	0.095
2017	1669	0.012	0.106	995	1.726	0.102
2018	1822	0.013	0.116	1121	1.999	0.110
2019	1751	0.012	0.112	1055	2.091	0.098
2020	585	0.005	0.038	974	2.291	0.086
2021	512	0.005	0.032	995	2.288	0.084
2022	1353	0.010	0.086	1034	1.544	0.084

Source: Statistics Norway/Norwegian Environment Agency.

3.2.2.2 Shipping

3.2.2.2.1 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.

3.2.2.2.2 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.

3.2.2.2.3 Emission factors

Emission factors used for shipping are described under *Navigation* in Section 3.2.9.4.

3.2.2.3 Aviation

3.2.2.3.1 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.

3.2.2.3.2 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 Norwegian 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).

3.2.2.3.3 Emission factors

Emission factors used for *Aviation* are described under *Aviation* in Section 3.2.6.4.

3.2.3 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.

3.2.3.1 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.

3.2.3.2 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.

3.2.3.3 CO_2 emissions from non-fuel use reported in 1A Fuel combustion

These emissions comprise the following categories, which are further described in section 3.2.13:

- 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.

3.2.3.4 CO_2 emissions from non-fuel use reported in the IPPU sector

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_2 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[17] 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.

[17] Including "fuel gas" which is reported as "Other oil products n.e.c." in the energy balance.

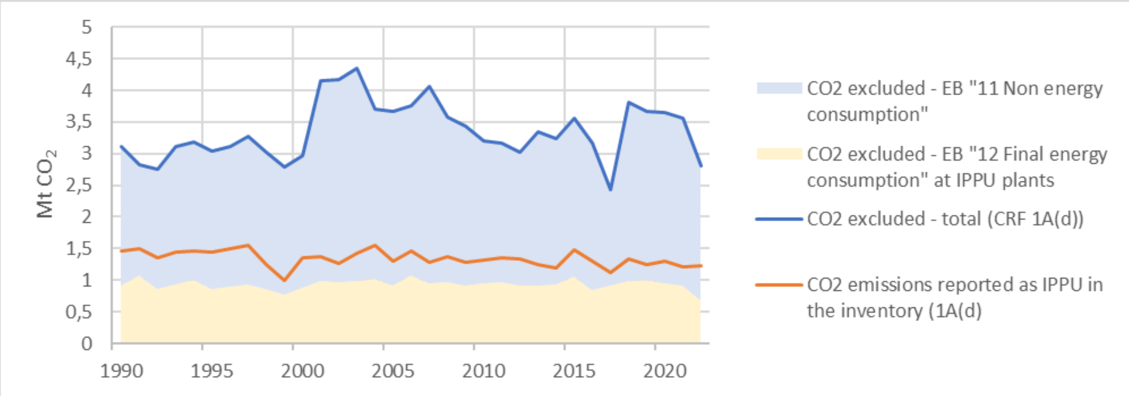


Figure 3.6: LPG. CO_2 amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:
- 2B1 Ammonia
- 2B8b Ethylene (including vinyl chloride reallocated from 2Bc)
- 2B8g Plastics (PE/PP production)
- 2H2 Food and beverage (CO_2 as product from ammonia production)

Figure 3.6 shows CO_2 excluded from the reference approach and CO_2 reported in IPPU. Non-fuel consumption according to the energy balance is shown in blue shading. CO_2 from fuels reported as energy use in the balance is shown in yellow shading. This corresponds to 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_2 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_2. 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.

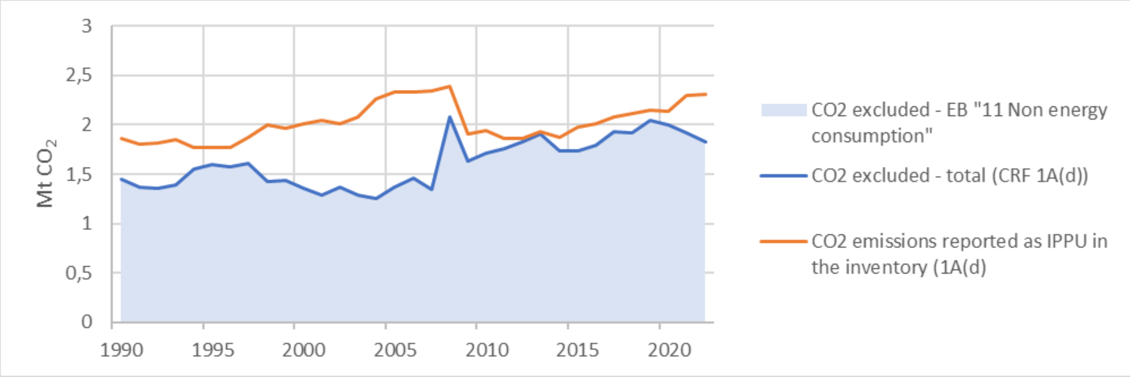


Figure 3.7: Petroleum coke. CO_2 amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:

- 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 3.7). 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_2 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 1A(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.

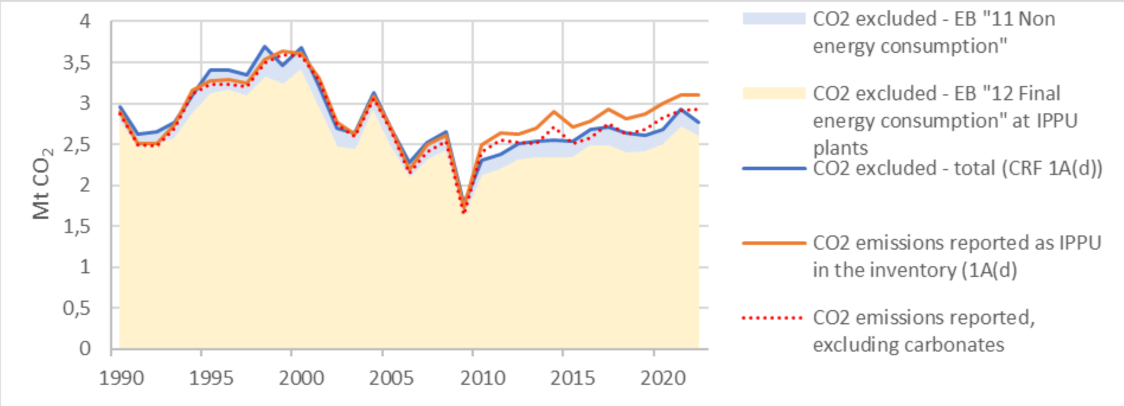


Figure 3.8: Coal and coke products. CO_2 amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:
- 2B6 Titanium dioxide
- 2C Metal production, excluding 2C3 and 2C7-anodes (petroleum coke) and 2C7-nickel (carbonates only)

Figure 3.8 shows CO_2 excluded from the reference approach and CO_2 reported in IPPU. In the energy balance, all coke and most of the coal is 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_2 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_2. When adjusted for carbonate CO_2, 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.

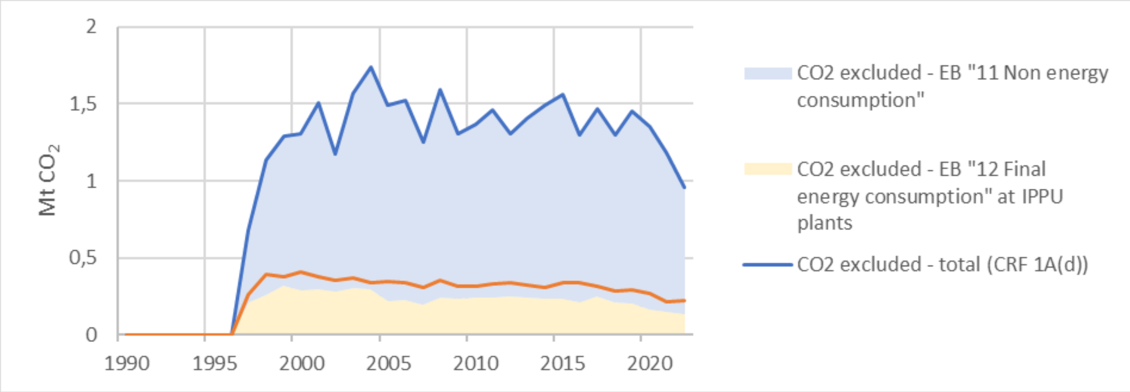


Figure 3.9: Natural gas. CO_2 amounts excluded from the reference approach (shaded areas, blue line) and reported as IPPU emissions (orange line). IPPU sectors reported in the inventory include:
- 2B8a Methanol

Figure 3.9 shows CO_2 excluded from the reference approach and CO_2 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_2 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_2 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.

3.2.4 Energy industries, 1A1 (Key category for CO_2 and CH_4)

3.2.4.1 Category 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 in the source category Energy industries (CRF 1A1). Emissions from combustion not for energy purposes, e.g., flaring, are included in section 3.3 and 7.5.

Emissions from drilling at moveable offshore installations are included in section 3.3. Emissions from these installations, while not in operation (during transport, etc.), are included with 1A3d Navigation.

Figures on natural gas used in turbines for pipeline transport at two separate facilities are reported annually from the Norwegian Offshore 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_2 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 are reported under 1A1, rather than under 1A3e.

In 2022, GHG emissions from the energy industries accounted for 38% of the energy sector's total emissions and 26% of the total emissions in Norway. Emissions increased by 77% during the period 1990-2022, primarily due to the increased activity in the oil and gas extraction sector.

According to the approach 2 key category analysis for 1990 and 2022, this sector is, in conjunction with stationary combustion in sectors 1A2 and 1A4, a key category with respect to:

- Emissions of CO_2 from the combustion of liquid fuels, gaseous fuels, and other fuels in level in 1990 and 2022, and in trend
- Emissions of CO_2 from the combustion of solid fuels in level in 1990 and 2022

- Emissions of CH_4 from the combustion of biomass and gaseous fuels in level in 1990 and 2022 and in trend

3.2.4.2 Methodological issues

A description of the general method used for estimating emissions from fuel combustion is given in section 3.2. However, most of the reported emissions in this source category are from the annual report from the entities to the Norwegian Environment Agency. The guidelines for estimating and reporting emissions are lengthy and in Norwegian, so instead of attaching these to the NIR, URLs are provided in Annex 5a.

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 reports 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_2O

Emissions of N_2O are derived from the emissions of NO_X, which are reported from each plant to the Norwegian Environment Agency. More specifically, an estimated amount of 2.5% of this NO_X is subtracted and reported to UNFCCC as N_2O (SFT 1996). Accordingly, the net NO_X emissions constitute 97.5% of the emissions reported by the plants. For some years, emissions of NO_X 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.

3.2.4.3 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 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 was of a somewhat larger size. Coal fired operations ended in October 2023, and the power plant is currently running on diesel. The amount of waste combusted at district heating plants is reported annually both to Statistics Norway and the Norwegian Environment Agency, see Table 3-12. Data are considered to be of high quality.

Table 3-12: Amount of waste combusted at waste incineration plants. Unit: 1000 tonnes.

Year	Amount of waste incinerated (1000 tonnes)
1990	225
1995	367
2000	524
2005	626
2010	1 044
2015	1 618
2016	1 562
2017	1 645
2018	1 677
2019	1 608
2020	1 643
2021	1 560
2022	1 596

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 Offshore 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_2 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 annex 5a. Annex 5a also 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; Offshore Norge 2023).

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 Offshore 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.

3.2.4.4 Emission factors

The emission factors used for energy industries are presented in section 3.2. For some industries and components, more information about the derivation of the emission factors is given below.

<u>Liquid fuels in electricity generation</u>

The CO_2 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 45 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 (Tonne CO_2/TJ fuel) is 20% lower (Table 3-4). 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_2 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.

<u>Gas in electricity generation</u>

The CO_2 implied emission factor for use of natural gas in electricity generation varies significantly over the period, from 55.1 t/TJ to 59.1 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.

<u>Coal in electricity and heat production</u>

The CO_2 factor for solid fuels in electricity generation is low, at 89.7 t/TJ. The emissions in this category are from coal use on Svalbard. The coal mined at Svalbard has a low carbon emission factor.

The CO_2 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.

<u>Waste incineration</u>

The emission factors for CO_2, CH_4 and N_2O from combustion of waste (fossil part only) are displayed in Table 3-4,

Table 3-5 and Table 3-7, respectively.

The CO_2 emission factor for the fossil part of waste combusted in waste incineration plants in Norway was revised in 2014 (Fedoryshyn 2015) and in 2023 (MEPEX 2020). The review in 2023 continue to build on the results from 2014. The amount of CO_2 per tonne plastic that is combusted varies with the type of plastic. It is assumed that mixed plastic contains 2 580 tonnes CO_2 per tonne plastic (Nielsen et al. 2010) and that 22.1% of the combusted waste was fossil in 2018, an increase from 20% in the 2014 review (Norwegian Climate and Pollution Agency 2011). The emission 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 1995-2009 and it is used linear interpolation in 2011-2015. In the years before 1995 are the 1995 emission factor used. In the years after 2018 is the CO_2 emission factor held constant as the 2018 factor.

The energy content of waste used in the calculation is 11.5 GJ per tonne waste and is based on a report from Avfall Norge (Marthinsen et al. 2010).

<u>Oil refineries</u>

The CO_2 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_2/tonne fuel or tonne CO_2/TJ. High hydrogen content leads to low emission factors as measured in tonne CO_2/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_2/TJ. In the Norwegian inventory, the emission factor varies in the range 46-62 tonne CO_2/TJ.

<u>Extraction of oil and natural gas</u>

Offshore operations

For all years up to 2002, emissions of CO_2 from gas combustion offshore are calculated by Statistics Norway based on activity data reported by the oil companies to the Norwegian Offshore 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 Environment Agency.

The CO_2 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 3-13 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 back towards fields with somewhat lower carbon content.

Activity data are reported in volume or mass terms, as noted in the AD section above. The preparation of the CO_2 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 3-13. The table shows factors both in kg CO_2/Sm^3 and kg CO_2/GJ. The factors fCO_{2_vol} in kg CO_2/Sm^3 are annual averages from total emission and consumption data as reported in Footprint. The factors fCO_{2_E} in kg CO_2/GJ are back-calculated from the fCO_{2_V} values using a formula from the reporting guidance document (Offshore Norge 2023):

$$fCO2\_vol = 0.0724 \cdot NCVvol + 0.5771$$

where fCO_{2_vol} is given in kg CO_2/Sm^3 and NCV_{vol} in MJ/Sm^3.

The formula is originally meant to estimate CO_2 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 $fCO_{2\_E} = fCO_{2\_vol} / NCV_{vol}$ and inserting the expression above, solved for NCV_{vol}, one gets

$$fCO2\_E = 0.0724 / (1 + 0{,}5771 / fCO2\_vol)$$

This formula is used to obtain the data for kg CO_2/GJ in the table.

Table 3-13: Average emission factors of CO_2 from the combustion of natural gas in turbines at offshore gas and oil fields.

Year	kg CO_2/Sm3	kg CO_2/GJ
1990	2.40	60.82
1995	2.38	59.10
2000	2.49	58.77
2005	2.45	58.60
2010	2.44	58.56
2015	2.41	58.42
2016	2.40	58.38
2017	2.38	58.27
2018	2.37	58.20
2019	2.33	58.05
2020	2.34	58.06
2021	2.34	58.10
2022	2.35	58.12

Gas terminals

There are four gas terminals in Norway. The CO_2 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_2 emission factors for fuel gas varies between terminals.

At the two terminals that account for most of the CO_2 emissions, some CO_2 derived from the natural gas feed is entered into the fuel gas. This leads to low CO_2 emissions per tonne gas and high emissions per MJ. In

Table 3-14, emission factors in t CO_2/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 3-14: Average emission factors of CO_2 from two major natural gas terminals. t CO_2/t fuel gas.

Year	Kårstø	Hammerfest
2013	2.26	2.49
2014	2.18	2.46
2015	2.20	2.46
2016	2.24	2.45
2017	2.23	2.45
2018	2.25	2.45
2019	2.28	2.45
2020	2.36	2.47
2021	2.55	2.67
2022	2.62	2.48

3.2.4.5 Uncertainty assessment and time-series consistency

The uncertainty analysis performed for the energy industries (Annex 2) has shown that the uncertainty in the activity data is ± 3% of the mean for oil, ± 4% for gas and ± 5% of the mean for coal/coke and waste.

In the case of the emission factors for CO_2, the uncertainty is ±3% of the mean for oil, ±3.5% for gas, ±7% for coal/coke and gas and ± 30% of the mean for waste.

Emission factors for CH_4 and N_2O 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_2 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.

3.2.4.6 Category-specific QA/QC and verification

The energy industries are subjected to the general QA/QC procedures described in section 1.5 and in Annex 5a QA/QC point sources. The category-specific QA/QC described in section 3.2 is also valid for Energy Industries.

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

<u>Extraction of oil and natural gas</u>

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.

<u>Oil refineries</u>

The CO_2 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.

3.2.4.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.2.4.8 Category-specific planned improvements

Implementation of a new emission factor for CO_2 from the biogenic fraction of waste is planned in 2024.

3.2.5 Manufacturing industries and construction, 1A2 (Key category for CO_2 and CH_4)

3.2.5.1 Category description

A description of the general method used for estimating emissions from fuel combustion is given in section 3.2. 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., 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).

CO_2 from combustion at petrochemical and ammonia plants are reported under industrial processes (CRF 2B). All CO_2 emissions from ammonia production are reported under 2B1.

The emissions reported in CRF 2B8 includes all CO_2 emissions from flaring and combustion of fuels derived from the natural gas feedstock. Minor CO_2 emissions from other energy combustion (diesel and propane) are included under 1.A.2.C.

Emissions from this sector contributed to 6% of the national GHG total in 2022, and 8% of the total emissions from the energy sector. Emissions from the sector decreased by 17% from 1990 to 2022.

According to the approach 2 key category analysis for 1990 and 2022, this sector is, in conjunction with stationary combustion in sectors 1A1 and 1A4, a key category with respect to:

- Emissions of CO_2 from the combustion of liquid fuels, gaseous fuels, and other fuels in level in 1990 and 2022, and in trend
- Emissions of CO_2 from the combustion of solid fuels in level in 1990 and 2022
- Emissions of CH_4 from the combustion of biomass in level in 1990 and 2022 and in trend

3.2.5.2 Methodological issues

A description of the general method used for estimating emissions from fuel combustion is given in section 3.2. For many plants the emission figures are based on reported figures from the plants to the Norwegian Environment Agency (see chapter 3.2). Indeed, in 2022, these plants accounted for 22% of the CO_2 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.

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 Annex 5a. Annex 5a also 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 2024) are consistent with the European Union's guidance documents (European Comission). A description of annual permit and reporting to the Norwegian Environment Agency is available at the Miljødirektoratet webpage (Veiledning til egenkontrollrapportering - Miljødirektoratet (miljodirektoratet.no)) .

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.

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 3.2.11.

1A2a Iron and steel

The iron and steel industry is a relatively small emission source in Norway, with emissions in the range of 55-85 kilotonnes per year. There is no domestic pig iron production. Most of the emissions are from an electro steel 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.

As described in 3.2 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_2 IEF time series.

For the Iron and steel industry, more than half of CO_2 emissions are directly reported in the period 1990-1996. From 1997 and onwards, all CO_2 emissions are directly reported. There are two point sources that have reported emissions to the Norwegian Environment Agency. 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. On average, around 65% of CO_2 energy emissions from the Iron and steel industry arises from combustion of solid fuels - almost exclusively blast furnace gas. Around 30% of emissions arise from liquid fuels.

Concerning reported CO_2 emissions per fuel type, the Iron and steel industry follows the general method from 1990-2007. Total CO_2 per plant is entered, and then allocated to fuel type based on the fuel share of the plants calculated emissions (see 3.2, Eq. 3). From 2008 onwards, reported fuel-specific CO_2 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 Statistics Norway subtracts the energy figures from the energy balance that are linked to the directly reported CO_2 emissions from the Norwegian Environment Agency. Sometimes there are inconsistencies between the energy data from the Norwegian Environment Agency and the energy data from Statistics Norway s 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 Statistics Norway, *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.

3.2.5.3 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 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, 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 diesel in the manufacturing industries and on reported sales of duty-free diesel to construction. The methods for calculating emissions are discussed in section 3.2.11.

3.2.5.4 Emission factors

Emission factors used in this source category are presented in detail section 3.2. 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_2 IEF for solid fuels in the iron and steel industry shows some variability. 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 ± 10% of the average IEF, but with some outlying years. This is likely due to inconsistencies between reported data in physical and energy terms. Variations in the time series for the CO_2 IEFs for solid and liquid fuels are discussed in the methodology section (3.2).

Pulp and paper (1A2d) – biomass

The CO_2 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_2/TJ and from wood waste with an emission factor of 111 t CO_2/TJ. In 2013, a large plant using black liquor closed. 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_4 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_4/TJ (

Table 3-5) and from wood waste with an emission factor of 30 kg CH_4/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_2 and N_2O are similar for the fuels, and the IEFs for these gases vary little among years.

3.2.5.5 Uncertainty assessment 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. A more detailed description is presented in Annex 2.

The EU ETS emission estimates are available for all years from 2005. For the time period 1990-2004 there are no data from ETS. This 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_2 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.

3.2.5.6 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 and in Annex 5a QA/QC of point sources.

3.2.5.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.2.5.8 Category-specific planned improvements

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

3.2.6 Transport – Civil Aviation, 1A3a (Key category for CO_2)

3.2.6.1 Category description

In 2022, emissions from domestic civil aviation amounted to 8% of the total emissions from transport and 2.2% of the GHG national total. From 1990 to 2019, these emissions increased by 61% due to activity growth. In 2020, the activity decreased caused by the covid-19 pandemic and the emissions sank by approximately 28% compared to 2019. Emissions have since rebounded and were 5% lower in 2022 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_2 emissions in level both in 1990 and in 2022 and in trend. Emissions of CH_4 and N_2O from this source category are insignificant.

3.2.6.2 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 3.2.2).

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.

3.2.6.3 Activity data

The types of fuels used in aircraft are both jet kerosene and aviation gasoline. The latter is used mostly in small aircraft. 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.

3.2.6.4 Emission factors

The N_2O and CH_4 emission factors used in the emission inventory for civil aviation are presented in Table 3-15 and

Table 3-16.

The Norwegian Petroleum Industry Association provides CO_2 emission factors for the combustion of jet kerosene and aviation gasoline (Finstad et al. 2002). The CO_2 emission factor used for aviation gasoline is 71.3 tonne CO_2 per TJ (Table 3-4) and has been applied to small aircraft and helicopters. Jet fuel (kerosene) has an emission factor of 73.09 tonne CO_2 per TJ (Table 3-4).

For N_2O, a default emission factor is used for all aircraft (IPCC) and is valid for both LTO and the cruise phase.

For CH_4 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_4 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 3-15: CH_4 and N2O emission factors (kg/Tj) in aviation. 2022.

Source	CH_4 kg/TJ		N_2O kg/TJ
	Aviation gasoline	Jet kerosene	Aviation gasoline / Jet Kerosene
Charter/scheduled flights			
LTO (0-1000 m)		**3.9**	2.3
Cruise (> 1000 m)			2.3
Helicopters			
LTO (0-1000 m)	43.1	74.2	2.3
Cruise (> 1000 m)			2.3
Small aircraft			
LTO (0-1000 m)	**16.6**	**16.9**	2.3
Cruise (> 1000 m)			2.3

Source: EEA (2019), Statistics Norway. Bold figures vary, see

Table 3-16

Table 3-16: CH_4 emission factors (kg/Tj) from jet kerosene and aviation gasoline in aviation, LTO. 1990-2022.

	Charter/ scheduled flights	Small aircraft	
Year	**Jet kerosene**	**Aviation gasoline**	**Jet kerosene**
1990-2010	4.34	9.8	9.9
2015	4.39	11.9	12.2
2016	4.31	11.4	11.6
2017	4.12	10.7	10.9
2018	3.96	10.7	10.9
2019	3.85	10.7	9.3
2020	5.0	9.8	10.0
2021	5.1	8.9	9.1
2022	3.9	16.6	16.9

Source: EEA (2019), Statistics Norway

3.2.6.5 Uncertainty assessment and time series consistency

The uncertainty in the activity data for civil aviation is estimated to be ±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.

The uncertainty in the CO_2 emission factors is ±3%. The uncertainty in the CH_4 and N_2O emission factors lies below and above the mean by a factor of 2 and 3, respectively.

3.2.6.6 Category-specific QA/QC and verification

The data are annually updated with emission factors and fuel consumption factors for new aircrafts in domestic and international traffic. The trend in CO_2 emissions is compared to the trend in domestic and international flights. If available, the consumption data is annually compared to the reported sales of jet kerosene to the Norwegian Tax Administration.

Annex 4 has a description of the general QA/QC procedure.

3.2.6.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

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 – Road Transportation, 1A3b (Key category for CO_2, CH_4 and N_2O)

3.2.7.1 Category description

Road traffic accounted for 68% of the total GHG emissions from transport and for 18% of the national GHG total in 2022.

Emissions from road traffic reached a maximum in 2015, with an increase of 39% since 1990. Since 2015, the emissions have been reduced by 16%, mainly due to use of biofuels, but increasingly due to the introduction of electric vehicles. Net increase for the inventory period 1990-2022 was 17%.

According to the approach 2 key category analysis, this sector is a key category with respect to emissions of CO_2 in level in 1990 and 2022, and trend. For CH_4 the sector is a key category with respect to trend, and for N_2O with respect to level in 1990 and 2022.

Since 1990, emissions from **passenger cars** (PCs) have decreased by 20%, while vehicle kilometers for PCs have increased by 55% and the number of PCs has grown by 80%. 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% from 2007 due to the CO_2 differentiated tax on new personnel 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 3.15, and hence contributed to the CO_2 emission decrease. Since then, the biofuel fraction has varied between 12 and 15% of total road fuels by volume. The biofuel fraction in 2022 was 13%.

Emissions from **light commercial vehicles** (LCV) and **heavy-duty vehicles** (HDV) increased by 103% and 90% respectively, during the period 1990-2022. 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_2 emissions from road traffic decreased from 68% in 1990 to 46% in 2022. LCVs and HDVs increased their contribution to total emissions from road traffic from 10 to 17%, and 21 to 35%, respectively, from 1990 to 2022.

Since 1990, economic growth has led to increased trade and consumption of goods. LCVs are used as private vehicles, goods transport and other business activities, and their share of the total emissions from road transport has increased. HDVs consist of trucks and buses but it is specifically goods transport with trucks that are responsible for the increase of emissions.

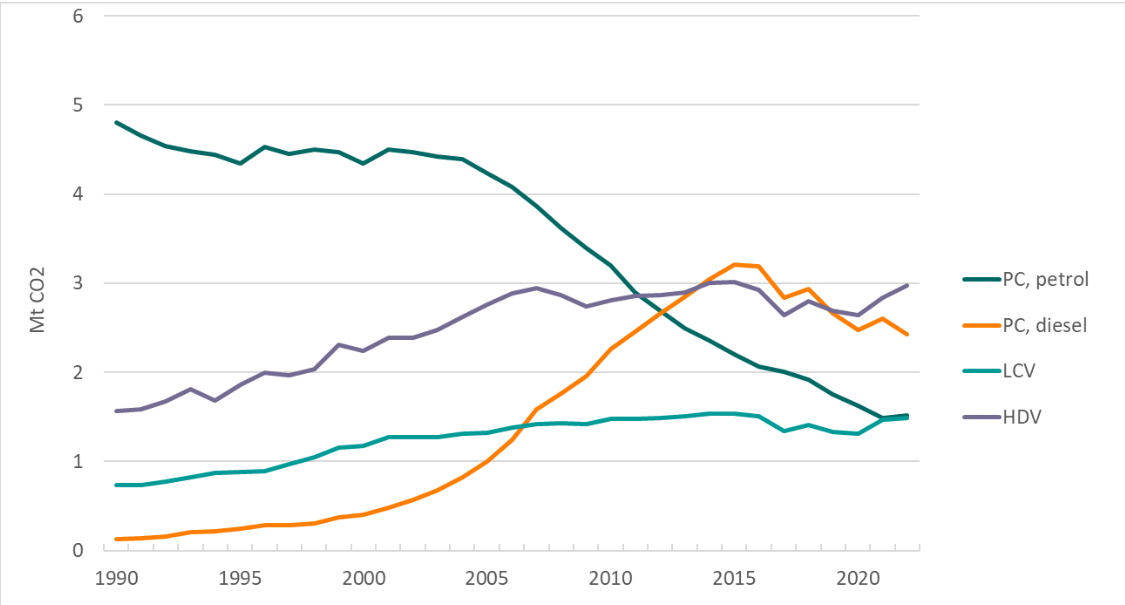


Figure 3.10: Emissions of CO2. PC petrol and diesel, LCV and HDV. Million tonnes CO2 equivalents. Source: Statistics Norway/Norwegian Environment Agency.

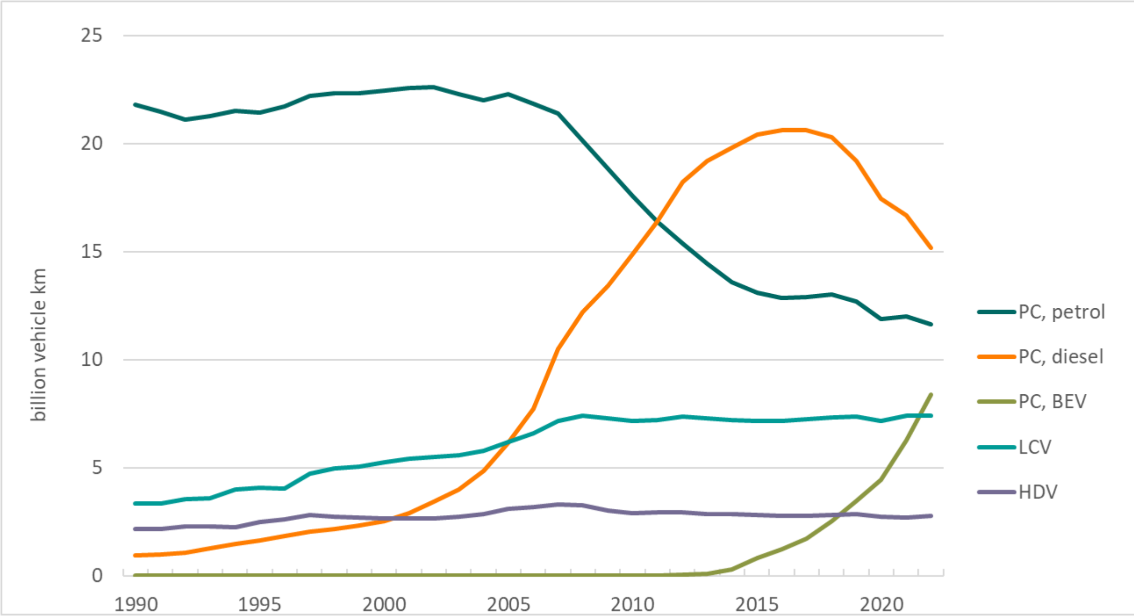


Figure 3.11: Vehicle kilometres. PC petrol and diesel, LCV and HDV. BEV = Battery electric vehicles. Source: Statistics Norway/Norwegian Environment Agency.

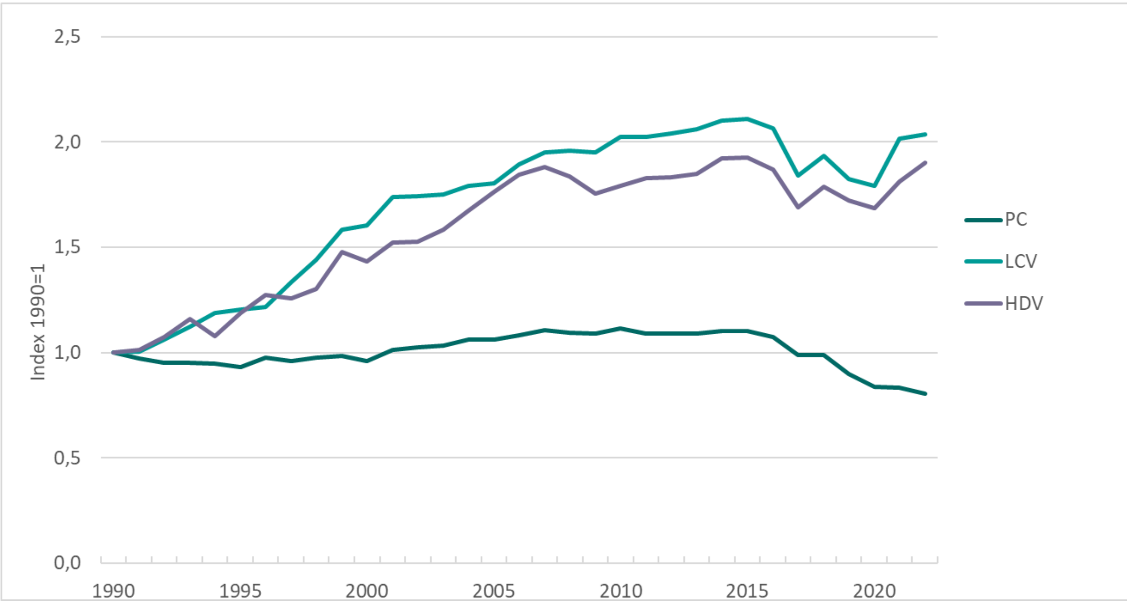


Figure 3.12: Relative change to 1990 in total CO_2 emissions from PC, LCV and HDV. Index 1990=1. Source: Statistics Norway/Norwegian Environment Agency.

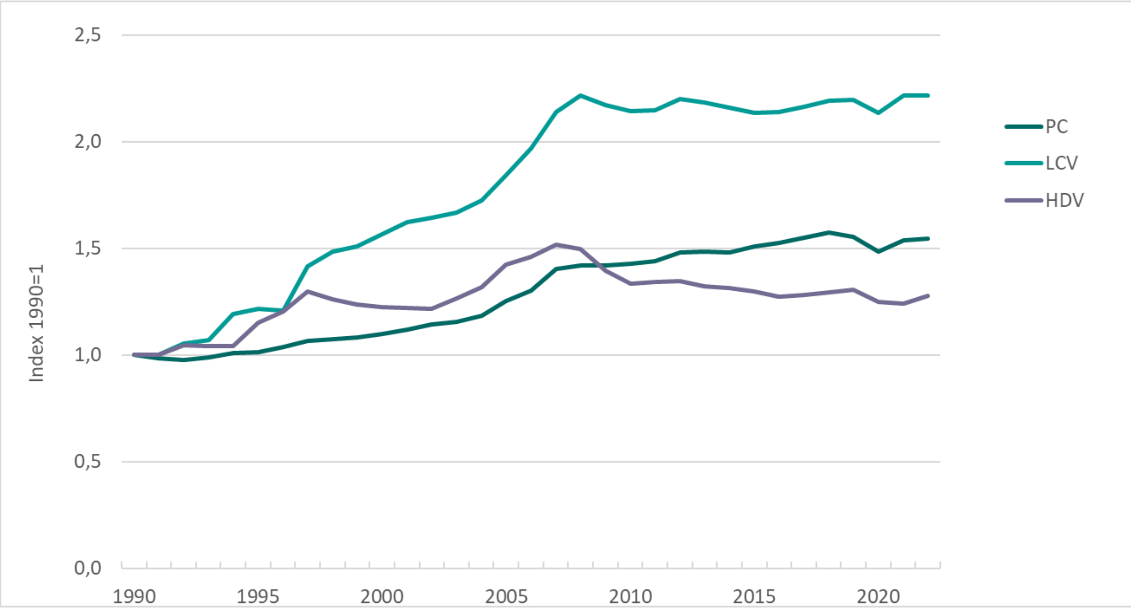


Figure 3.13: Relative change to 1990 in total vehicle km. PC, LCV, HDV. Index 1990=1. Source: Statistics Norway/Norwegian Environment Agency.

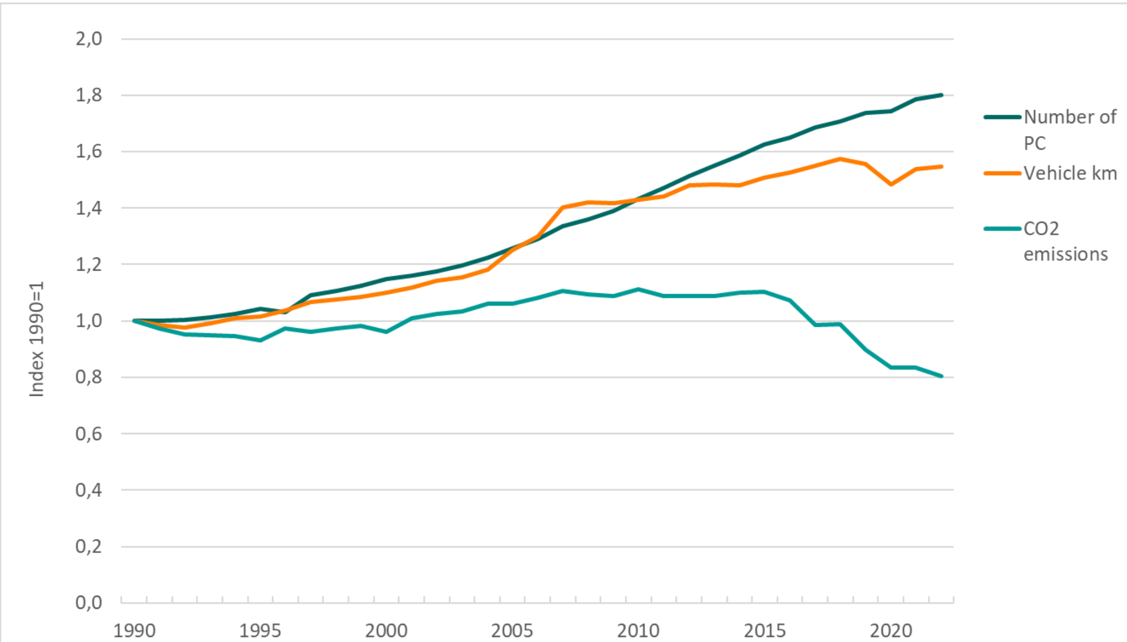


Figure 3.14: Relative change to 1990 in number of passenger cars, CO_2 emissions and vehicle kilometers. Index 1990=1. Source: Statistics Norway/Norwegian Environment Agency.

3.2.7.2 Methodological issues

Total emissions of CO_2 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. leisure boats, snow mobiles and motorized equipment. For diesel, the total consumption in road traffic is all diesel, including biodiesel, charged with auto diesel tax. Other use of diesel, without diesel tax, is 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_4 and N_2O are estimated by the HBEFA model (INFRAS 2022). The model uses a mileage approach:
*Emissions = mileage * 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 3-17.

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, stop and go, stop and go gridlock). 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. 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 3-17: 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
Urban bus	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
Motorcycles and mopeds	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

3.2.7.3 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 railways, leisure boats, snow scooters and motorized equipment). 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.*15, 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 2022, the share of biofuel in fuel sales was 13%.

- *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 31st 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 motorcycles 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.

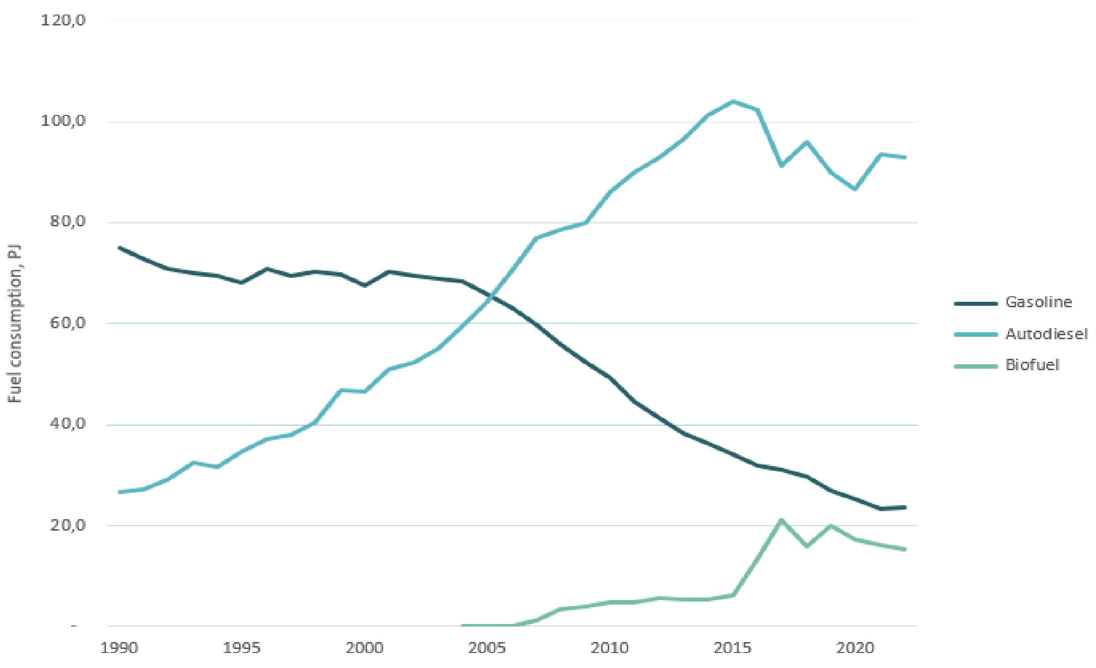


Figure 3.15: Consumption of gasoline, diesel and biofuel for road transportation. PJ. Source: Statistics Norway.

3.2.7.4 Emission factors

Emission factors (except CO_2) are from the Handbook of Emission Factors (INFRAS 2022). Factors are given as emission per vehicle kilometres for detailed combinations of subsegments and traffic situations.

Emission factors for CO_2 are given by fuel type in Table 3-4. The factor for fossil motor gasoline is 71.3 tonne CO_2 per TJ, while the factor for diesel is 73.55 tonne CO_2 per TJ. The CO_2 factors used for ethanol is 71.27 tonne CO_2 per TJ and for biodiesel 77.45 tonne CO_2 per TJ.

Table 3-18 - Table 3-21 shows average emission factors in gram per kilometres for different vehicle categories and fossil fuels estimated in HBEFA.

Table 3-18: Average CO_2 emission factors for different vehicle categories, including cold start emissions and evaporation. The share of biofuels is not reflected in these numbers i.e., they show the emission factors of fossil fuels.

Year	Motor gasoline g/km				Diesel g/km		
	Passenger cars[1]	Light commercial vehicles	Heavy duty vehicles	Motorcycles	Passenger cars1	Light commercial vehicles	Heavy duty vehicles
1990	191.3	199.6	557.4	76.5	163.4	233.1	828.7
1995	189.3	202.1	557.7	86.5	163.2	234.9	815.9
2000	183.7	200.9	557.2	98.3	158.9	231.1	859.4
2005	178.4	187.1	556.4	94.9	159.1	213.6	894.6
2010	173.4	179.9	560.8	94.7	150.3	204.7	969.1
2011	171.4	179.1	560.9	94.8	147.9	203.7	975.9
2012	168.9	179.2	561.0	95.0	146.0	202.5	981.4
2013	165.5	179.7	561.0	95.4	145.1	201.6	987.3
2014	161.9	179.6	561.0	96.0	144.7	200.2	992.6
2015	158.3	179.2	557.2	96.7	144.7	198.5	985.4
2016	155.4	179.3	557.2	97.5	145.0	197.4	991.1
2017	152.1	179.3	557.2	97.9	145.4	195.5	1 002.2
2018	149.3	177.2	557.2	97.8	145.6	193.5	1 003.8
2019	147.8	175.8	557.2	97.4	146.1	191.5	1 000.8
2020	145.6	174.2	557.1	97.2	146.3	189.3	1 007.5

2021	144.2	174.6	557.0	96.9	146.4	189.0	1 003.6
2022	142.4	172.5	556.5	95.0	146.2	186.5	998.1

Source: Statistics Norway, HBEFA 4.2. [1] Excluding plugin hybrid vehicles

Table 3-19: General CH_4 and N_2O emission factors from natural gas and LPG in passenger cars and heavy-duty vehicles in 2022.

Source	Fuel	CH_4 kg/TJ	N_2O kg/TJ
Passenger cars	LPG	24.6	0.91
Heavy duty vehicles	Natural gas	11.72	5.32

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

Table 3-20: Average CH_4 emission factors on vehicle category, including cold start emissions and evaporation.

	Motor gasoline g/km				Diesel g/km		
	Passenger cars[1]	Other light duty vehicles	Heavy duty vehicles	Motor-cycles	Passenger cars[1]	Other light duty vehicles	Heavy duty vehicles
1990	0.1193	0.1227	0.1566	0.2107	0.0069	0.0053	0.0308
1995	0.0939	0.1065	0.1566	0.1834	0.0052	0.0049	0.0268
2000	0.0592	0.0797	0.1567	0.1990	0.0039	0.0034	0.0158
2005	0.0371	0.0556	0.1568	0.3002	0.0029	0.0024	0.0113
2010	0.0271	0.0417	0.1558	0.2813	0.0025	0.0017	0.0065
2011	0.0258	0.0408	0.1558	0.2794	0.0028	0.0019	0.0055
2012	0.0243	0.0398	0.1558	0.2761	0.0030	0.0021	0.0049
2013	0.0227	0.0391	0.1558	0.2714	0.0033	0.0025	0.0044
2014	0.0211	0.0385	0.1558	0.2662	0.0035	0.0028	0.0037
2015	0.0196	0.0381	0.1563	0.2591	0.0039	0.0031	0.0032
2016	0.0183	0.0378	0.1563	0.2523	0.0046	0.0036	0.0028
2017	0.0170	0.0365	0.1563	0.2440	0.0052	0.0042	0.0024
2018	0.0158	0.0354	0.1563	0.2321	0.0056	0.0048	0.0021
2019	0.0151	0.0348	0.1563	0.2210	0.0059	0.0057	0.0018
2020	0.0143	0.0345	0.1563	0.2093	0.0061	0.0068	0.0018
2021	0.0140	0.0344	0.1563	0.1973	0.0062	0.0075	0.0016
2022	0.0135	0.0332	0.1563	0.1940	0.0063	0.0082	0.0014

Source: Statistics Norway, HBEFA 4.2. [1] Excluding plugin hybrid vehicles

Table 3-21: Average N2O emission factors on vehicle category, including cold start emissions and evaporation.

	Motor gasoline g/km				Diesel g/km		
	Passenger cars[1]	**Other light duty vehicles**	**Heavy duty vehicles**	**Motorcycles**	**Passenger cars[1]**	**Other light duty vehicles**	**Heavy duty vehicles**
1990	0.0072	0.0068	0.0071	0.0013	0.0000	0.0000	0.0088
1995	0.0093	0.0083	0.0071	0.0014	0.0002	0.0004	0.0087
2000	0.0098	0.0113	0.0071	0.0016	0.0026	0.0030	0.0090
2005	0.0052	0.0104	0.0071	0.0015	0.0039	0.0040	0.0077
2010	0.0042	0.0078	0.0071	0.0016	0.0046	0.0044	0.0153
2011	0.0038	0.0074	0.0071	0.0016	0.0049	0.0046	0.0204
2012	0.0034	0.0069	0.0071	0.0016	0.0052	0.0048	0.0243

2013	0.0029	0.0063	0.0071	0.0016	0.0055	0.0050	0.0269
2014	0.0024	0.0058	0.0071	0.0016	0.0057	0.0052	0.0314
2015	0.0021	0.0053	0.0071	0.0016	0.0059	0.0055	0.0347
2016	0.0018	0.0048	0.0071	0.0016	0.0063	0.0059	0.0377
2017	0.0015	0.0042	0.0071	0.0016	0.0066	0.0065	0.0399
2018	0.0013	0.0037	0.0071	0.0016	0.0069	0.0071	0.0416
2019	0.0012	0.0034	0.0071	0.0016	0.0071	0.0077	0.0430
2020	0.0010	0.0030	0.0071	0.0017	0.0073	0.0083	0.0436
2021	0.0010	0.0029	0.0071	0.0017	0.0074	0.0088	0.0452
2022	0.0009	0.0027	0.0071	0.0017	0.0076	0.0092	0.0459

Source: Statistics Norway, HBEFA 4.2. [1] Excluding plugin hybrid vehicles

The N_2O emission factor in the HBEFA is from the COPERT IV model. In addition to the "normal" reduction of the emission factor according to the Euro-classes, the N_2O emission factor is influenced by the sulphur content. Indeed, a lower sulphur content of gasoline leads to a reduced deactivation of the catalyst and reduced N_2O 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_2O emission factor between 2004 and 2005. Similar development in the N_2O emission factor can also be seen in countries, which also use the HBEFA model, e.g., Switzerland and Sweden.

In the inventory, the same emission factors for CH_4 and N_2O are used for biofuels as for corresponding fossil fuels. Thus, the average implied emission factor for biomass in road transport is a function of the fractions of ethanol and biodiesel in the biofuel mix. Initially, the biofuel amounts were almost exclusively biodiesel, but in recent years ethanol has had a growing share of the mix.

3.2.7.5 Uncertainty assessment and time series consistency

The uncertainty in the activity data and the CO_2 emissions from road transportation is found to be ±5% and ±3% of the mean, respectively. In the case of CH_4 and N_2O, the uncertainty in the emission factors are ±45 and ±65, respectively (Gustafsson 2005). A detailed description of the uncertainty analysis is given in Annex 2.

The total consumption of petrol and diesel, and hence the CO_2 emissions from these fuels, are well known. The uncertainty for petrol and diesel is related to allocation to off-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.

3.2.7.6 Category-specific QA/QC and verification

The consumption of gasoline and diesel for road traffic in the energy balance is estimated as total sales minus consumption for other uses, i.e., a top-down approach. The HBEFA emission model makes bottom-up estimates of consumption. The top-down and bottom-up data on fuel consumption are compared on an annual basis. The discrepancies are further explained in section 3.2.7.3.

Annex 4 has a description of the general QA/QC procedure.

3.2.7.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.2.7.8 Category-specific planned improvements

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

3.2.8 Transport – Railways, 1A3c

3.2.8.1 Category 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 2022, GHG emissions from this source category accounted for 0.5% of the total emissions from transport. Emissions from railways decreased by 47% from 1990 to 2022.

3.2.8.2 Methodological issues

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

3.2.8.3 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 leisure boats. Consumption of coal is estimated based on information from different museum railways; the same figure is used for all years from 1990.

3.2.8.4 Emission factors

The emission factors used in this source category are displayed in Table 3-4 for CO_2 and Table 3-22 for CH_4 and N_2O.

General emission factors for coal are used in the calculations.

Table 3-22: General CH_4 and N_2O emission factors from diesel use in railways.

Source	Fuel	CH_4 kg/TJ	N_2O kg/TJ
Railway	Diesel	4.18	27.84

Source: Winther and Nielsen (2006); IPCC (2006)

3.2.8.5 Uncertainty assessment 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_2 is ±3% of the mean, whereas for CH_4 and N_2O, the uncertainty is ± 25% of the mean.

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

3.2.8.6 Category-specific QA/QC and verification

The diesel consumption from the Energy balance is annually compared with data on consumption reported to Statistics Norway on rail transport statistics.

Annex 4 has a description of the general QA/QC procedure.

3.2.8.7 Category-specific recalculations

There are no recalculations performed for this source category this year.

3.2.8.8 Category-specific planned improvements

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

3.2.9 Transport – Navigation, 1A3d (Key category for CO_2 and CH_4)

3.2.9.1 Category 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 3.2.11.

Greenhouse gas emissions from navigation constituted 6% of the national GHG total in 2022 and 23% of emissions from transport. Emissions from shipping have increased by 74% from 1990 to 2022. The increased emissions in the 90s can be largely 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 increased 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_2 and CH_4 emissions in level both in 1990 and in 2022, and in trend.

3.2.9.2 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 3.2.4 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 3.2.2), 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.

3.2.9.3 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.

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 fishing and 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 is based on sales figures reported to Statistics Norway from the distributors.

3.2.9.4 Emission factors

$\underline{CO_2}$

For CO_2 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_4 and N2O

For liquid fuels, the general/standard emission factors for CH_4 and N_2O used in the emission inventory are taken from IPCC/OECD: 0.23 kg CH_4/tonne fuel and 0.08 kg N_2O/tonne fuel.

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

- CH_4: 0.8 kg/tonne marine gas oil/diesel; 1.9 kg/tonne heavy fuel oil
- N_2O: 0.02 kg/tonne marine gas oil/diesel.

Some natural gas is combusted as LNG on board vessels; the CH_4 emission factors used are based on the emission factors in Table 3-23. 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.

The IPCC factor for N_2O from liquid fuels is also used for LNG.

Table 3-23: Methane emission factors for vessels using LNG as fuel gas.

Vessel category	Methane emission factor (kg CH_4 /tonne LNG)	Methane emission factor (kg CH_4/ TJ)
Ferry (Currently lean burn engines only)	44	917
Offshore supply (Currently dual fuel engines only)	80	1668

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

Table 3-24: Methane emission factors for vessels using LNG as fuel gas.

Year	Methane emission factor	Methane emission factor
	(kg CH_4 /tonne LNG)	(kg CH_4/ TJ)
1990-2002	44	917
2003	70.3	1 464
2004	74.0	1 541
2005	74.2	1 546
2006	74.0	1 543
2007	50.1	1 043
2008	52.8	1 101
2009	56.6	1 180

2010	58.1	1 211
2011	55.3	1 153
2012	49.9	1 040
2013	47.0	980
2014	44.7	931
2015 -	44.2	921

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

3.2.9.5 Uncertainty assessment 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. In addition, fuel bunkered abroad but combusted between two Norwegian ports are not included in the sales data. 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 ±20%. With regard to emission factors the uncertainty for ships and fishing vessels is ±3% of the mean for CO_2. For CH_4 and N_2O the corresponding uncertainties are ±25% of the mean (see also Annex 2).

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

A comparison of inventory emission data (based on petroleum sales in Norway) against emissions calculations based on AIS data, was carried out by the Norwegian Environment Agency in 2021 (Norwegian Environment Agency 2021). AIS based methodology resulted in somewhat higher emissions (approximately 1 million tonnes pro anno). The study concluded that differences in system limits were the most likely cause of the differences in emissions: AIS based methodology will include emissions from bunkering overseas.

3.2.9.7 Category-specific recalculations

There are no recalculations in this source category this year.

3.2.9.8 Category-specific planned improvements

The Norwegian Coastal Administration has since 2011 used a model based on Automatic Identification System (AIS) data to estimate the emissions from ships to air. The Norwegian Environment Agency was co-financing the development project. In 2015, the delimitation of activities was improved to correspond better to definitions in the inventory. The Norwegian Coastal Administration is currently developing a new and improved model, which is planned to replace the current model from 2024. A project in collaboration with Statistics

Norway and the Norwegian Coastal Administration is currently looking into how this new model can be used to improve or verify the inventory for navigation.

3.2.10 Transport – Other transportation, 1A3e

3.2.10.1 Category description

In old submissions, this source category included emissions from motorized equipment. In later submissions, emissions have been reported under the accurate sectors according to the guidelines (IPCC 2006) i.e., CRF 1A2, 1A4 and 1A5.

Figures on natural gas used in turbines for pipeline transport are reported under 1A1 Energy Industries, see chapter 3.2.4.1.

3.2.11 Motorized equipment (incl. in 1A2, 1A4 and 1A5)

3.2.11.1 Category description

The category *motorized equipment* comprises off-road transportation and other machinery, which are all mobile combustion sources except on road, sea, air, and railway. Equipment used in agricultural and construction sector are the most important categories. Other categories include mines and quarries, forestry, snow scooters, leisure 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 – see section 3.2.13

Primarily consumption of gasoline and diesel is considered. A small amount of fuel oil used for equipment in construction is also accounted for.

3.2.11.2 Methodological issues

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

3.2.11.3 Activity data

Gasoline and diesel are handled differently. They are both based on data from the energy balance. Diesel used in off-road transportation and other machinery is tax-free since 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.

<u>1A4b-ii households</u>

The consumption of gasoline and tax-free diesel in leisure boats 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. For the data year of 2022 the model was not used as normal. This was due to uncertainty about the quality of the results emerging from the model when updated with 2022-data from the boating survey. Instead, an estimate for the developement in total fuel consumption for leisure boats from 2021–2022 was used. The method for leisure boats is being revised in 2024.

The gasoline consumption in snow scooters is based on the number of scooters, annual mileage, and consumption per kilometres 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.

Smaller motorized equipment on gasoline (e.g., chainsaws and lawn mower) is calculated using 2% of the gasoline consumption in households (including bioethanol) deducted consumption for leisure boats.

<u>Motorized equipment other than household</u>
The figures for consumption of off-road diesel in agriculture (e.g., in tractors) 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).

Consumption of off-road diesel in forestry, manufacturing, and construction, commercial and institutional is covered by the annual statistics on sales of petroleum products. Distributor sales are broken down by industry according to distribution formulas.

3.2.11.4 Emission factors

The emission factors used are presented in Table 3-4 for CO_2, and

Table 3-20 and Table 3-25 for CH_4 and N_2O.

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 (HBEFA).

Table 3-25: General emission factors for other mobile sources.

Source	Fuel	CH_4 kg/TJ	N_2O kg/TJ
Leisure boats 2-stroke	Motor gasoline	116.17	0.46
Leisure boats 4-stroke	Motor gasoline	38.72	1.82
	Diesel	4.18	0.70
Motorized equipment 4-stroke	Motor gasoline	**50.11**	1.59
Motorized equipment 4-stroke	Diesel	3.94	**3.22**

Source: Bang (1993); SFT (1999d); Statistics Norway (2014a)
Snow scooters have the same emission factors as mopeds. Bold figures have exceptions for some sectors, see Table **3-26**

Table 3-26: Exceptions from the general factors for greenhouse gases and precursors for other mobile sources.

Component	Emission factor (kg/TJ)	Fuel	Source	Sectors
CH_4	125.28	Motor gasoline	Motorized equipment 4-stroke	Private households
N_2O	3.05	Diesel	Motorized equipment 4-stroke	Agriculture and forestry

Source: Bang (1993); SFT (1999d); Statistics Norway (2014a)

3.2.11.5 Uncertainty assessment and time series consistency

The total consumption of gasoline and diesel is well known, but the estimated consumption allocated on the off-road sources are considered quite uncertain (see Annex 2).
A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

3.2.11.6 Category-specific QA/QC and verification

There is no category-specific QA/QC procedure for this sector. See Annex 4 for a description of the general QA/QC procedure.

3.2.11.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.2.11.8 Category-specific planned improvements

The method for leisure boats is being revised in 2024.

3.2.12 Other Sectors, 1A4 (Key category for CO_2 and CH_4)

3.2.12.1 Category description

The source category *Other Sectors* includes stationary and mobile combustion in agriculture, forestry, fishing, commercial and institutional industries, and households. Section 3.2.11 describes mobile combustion in motorized equipment (off-road vehicles and other machinery).

In 2022, the emissions from this sector amounted to about 3.1 million tonnes CO_2 equivalents, which is 6% of national total GHG. The sector emissions decreased by 29% from 1990 to 2022. 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 2022, this sector is, in conjunction with stationary combustion in sectors 1A1 and 1A2, a key category with respect to:

- Emissions of CO_2 from the combustion of liquid fuels, gaseous fuels, and other fuels in level in 1990 and 2022, and in trend
- Emissions of CO_2 from the combustion of solid fuels in level in 1990 and 2022
- Emissions of CH_4 from the combustion of biomass and gaseous fuels in level in 1990 and 2022 and in trend

3.2.12.2 Activity data

Households

Activity data on mobile combustion in off-road vehicles and other machinery is described in section 3.2.11.

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 4th 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 3rd 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.

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 3.2.11.

<u>Agriculture</u>
Activity data on mobile combustion in off-road vehicles and other machinery is described in section 3.2.11.

Consumption of 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. 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. 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.

<u>Fishing</u>
Activity data on mobile combustion in off-road vehicles and other machinery is described in section 3.2.11.

Consumption of 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.

<u>Commercial and institutional sectors</u>
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.

3.2.12.3 Emission factor

The emission factors used in this source category are presented in sections 3.2 and 3.2.11. 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 Morten 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.

3.2.12.4 Uncertainty assessment and time-series consistency

Uncertainty in fishing is described together with navigation in section 3.2.9.

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 ±20% of the mean for solid and liquid fuels, and ±30% of the mean for biomass and waste (see Annex 2).

3.2.12.5 Category-specific QA/QC and verification

There is no category-specific QA/QC procedure for this sector. Annex 4 has a description of the general QA/QC procedure.

3.2.12.6 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.2.12.7 Category-specific planned improvements

A revision of the CO_2 emission factor and activity data for wood burning is planned this year.

3.2.13 Other emissions from energy combustion, 1A5 (Key category for CO_2)

This source includes emissions from fuel use in military stationary and mobile activities, and the use of lubricants in mobile combustion.

In 2022, the emissions from this sector amounted to about 0.1 million tonnes CO_2 equivalents, which is 0.2% of national total GHG. The sector emissions decreased by 81% from 1990 to 2022. The trend fluctuates significantly, mainly due to annual changes in military procurement.

3.2.13.1 Category description

Military

Emissions of CO_2 from the other mobile sub-sector (1A5b) is a key category according to approach 2 with respect to CO_2 emissions in trend.

Emissions from non-fuel use of liquid fuels

In the energy balance, small amounts of gasoline, 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_2. As lubricant, oil in two-stroke petrol is not included in the Norwegian energy statistics, a separate estimation must be performed to obtain completeness.

3.2.13.2 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 and emission factors used for mobile activities are presented in the corresponding transport sectors (see sections 3.2.6 to 3.2.11). The stationary and mobile emissions from the Norwegian military activities are presented in CRF 1A5a and 1A5b.

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_4/TJ and 0,6 kg N_2O/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_2 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:

$$3. \quad E = A \times R \times D$$

where:

E = emission

A = consumed two-stroke petrol

R = blend ratio (oil:petrol)

D = share of two-stroke petrol being blended domestically

The conversion from tonnes of consumed lubricant to tonnes of emitted CO_2, is performed based on IPCC default factors for energy content (NCV) and carbon content per unit of energy.

Table 3-27: Conversion factors used to estimate CO_2 emissions.

Factor	Value	Unit
Net calorific value (NCV)	0.0402	TJ/tonne
Carbon content (CC)	20	Tonne C/TJ

Source: IPCC (2006)

N_2O and CH_4 emissions have been estimated as fixed fractions of the CO_2 emission, based on IPCC default factors.

Table 3-28: Conversion factors used to estimate CH_4 and N2O emissions.

Factor	Value	Unit

CH_4	0.00286	Tonne CO_2 eq/tonne CO_2 emitted
N_2O	0.00254	Tonne CO_2 eq/tonne CO_2 emitted

Source: IPCC (2006)

3.2.13.3 Uncertainty assessment and time-series consistency

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 3.2.7). 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%.

3.2.13.4 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.2.13.5 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 solid fuels and oil and natural gas and other emissions from energy production (CRT 1.B)

3.3.1 Fugitive Emissions from Coal Mining and Handling, 1B1 (Key category for CH_4)

3.3.1.1 Category description

Coal has been shipped from Svalbard since 1907. In 2022 one coal mine (mine 7 near Longyearbyen) at Spitsbergen (the largest island in the Svalbard archipelago) was operated by a Norwegian company. This mine is producing coal for export. The mines at Svea, 60 kilometers south of Longyearbyen, ended production in 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 Longearbyen and at Pyramiden are defined as surface mines, whereas the mine in Barentsburg is an underground mine.

Abandoned underground mines are 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 3.16 illustrates. The emissions from this fire are included in the inventory under 1B1b Solid fuel transformation. The CO_2 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_2 from emissions of CH_4 and NMVOC are reported separately in CRF Table 6.

The total emissions from mining, including abandoned mines, is reduced by 57% from about 183 kilotonne in 1990 to 78 kilotonne CO_2 equivalents in 2022. In 2022 abandoned mines represented 67% of total emissions from source category 1.B.1. The emissions from mining, excluding from abandoned mines, were in 2022 estimated to 26 kilotonnes of CO_2 equivalents. The emissions, excluding from abandoned mines, decreased by 1% from 2021 to 2022. Total coal production was flat.

Figure 3.16 shows that the production of coal at Svalbard has decreased by 73% from 1990 to 2022. There was a peak in the production in 2007 when the production was five times higher than in 1990.

CH_4 from coal mining is defined as key category according to Approach 2 in both level in 1990 and 2022 and trend.

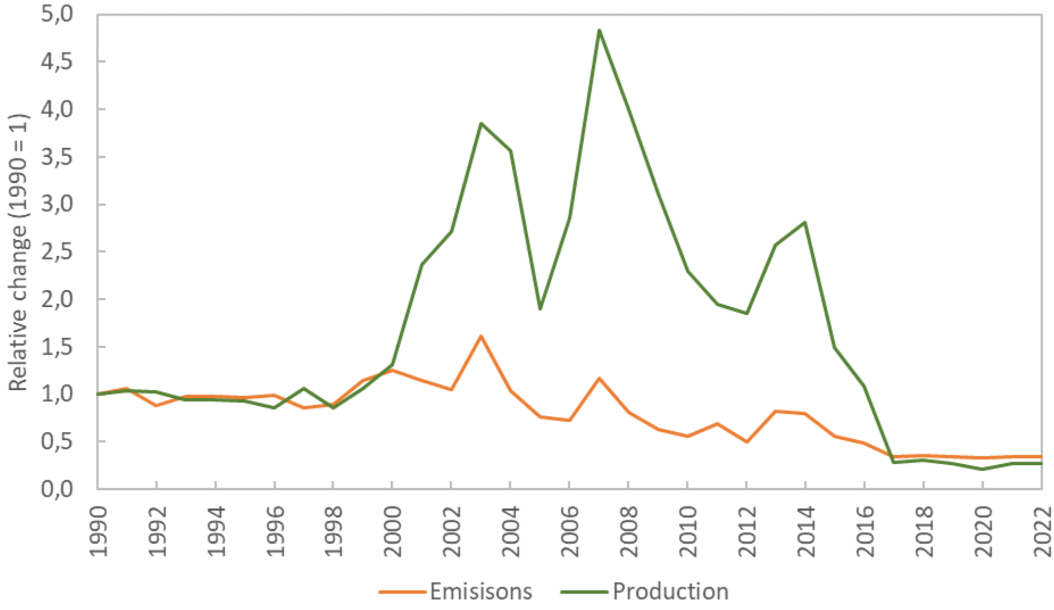


Figure 3.16: Relative change in coal production in Norway and related GHG emissions. Excluding emissions from abandoned underground mines. 1990=1.

3.3.1.2 Methodological issues

3.3.1.2.1 CO_2

See Chapter 9 for more information about indirect CO_2.

3.3.1.2.2 CH_4

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.

3.3.1.2.3 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).

3.3.1.2.4 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:

$$CH_4\ emissions = Number\ of\ abanodoned\ coal\ mines\ remaining\ unflooded \\ * Fraction\ of\ gassy\ coal\ mines * Emission\ factor * Conversion\ factor$$

The conversion factor is the density of CH_4 and converts volume of CH_4 to mass of CH_4. The conversion factor (density) has a value of 0.67 $*10^{-6}$ Gg m^{-3}.

3.3.1.3 Activity data

Figures on Norwegian production (raw coal production) is 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.

- 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 3-29 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 3-29: 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.

3.3.1.4 Emission factors

3.3.1.4.1 CH_4

For Norwegian coal production a country specific emission factor of CH_4 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 samples yielded an estimate of seam gas content of 0.535-1.325 m^3 methane per tonne coal derived from an average content of 0.79 m^3 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^3 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 CH_4 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.

3.3.1.4.2 NMVOC

Emission factors for NMVOC are taken from (EEA 2023). 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.

3.3.1.4.3 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 the Directorate for Mining with the Commissioner of Mines at Svalbard.

Default emission factors from the tier 1 methodology of the IPCC Guidelines (IPCC 2019) are used (Table 3-30). The complete table may be found as table 4.1.6 in volume 2 of the guidelines.

Table 3-30: Emission factors used for calculating emissions from abandoned underground mines. Million m^3 CO_2 /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
2022	0.235	0.268	0.322	0.425	0.542

Source: IPCC (2019)

3.3.1.5 Uncertainty assessment 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 CH_4 emissions from.

3.3.1.6 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 1.5 for general QA/QC procedures.

For abandoned underground mines no category-specific QA/QC routines are in place for the emission estimates.

3.3.1.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.3.1.8 Category-specific planned improvements

Implementation of CO_2 emission factors from the 2019 refinement to the reporting guidelines (IPCC 2019) is planned in 2024.

3.3.2 Fugitive Emissions from Oil and Natural Gas – 1B2

3.3.2.1 Overview

By turn of the year 2022/2023, 92 offshore fields were producing oil and gas on the Norwegian continental shelf. Four new fields started production in 2023. A further fifteen fields were under development at the end of the year (Minstry of Energy 2024).

The overall trend is that the total production of oil, gas and NGL and condensate increased to peak production of 264 mill. Sm^3 o.e. in 2004 and has since varied between 201 and 240 mill. Sm^3 o.e. (Figure 3.17). The increase in production from 1990 to 2004 was 111%. In 2022, the total production was 87% higher than in 1990, but unchanged between 2021 and 2022. From 2021 to 2022, oil production decreased by 5% while gas production increased by 8%. For more information about the Norwegian petroleum sector see Minstry of Energy (2024).

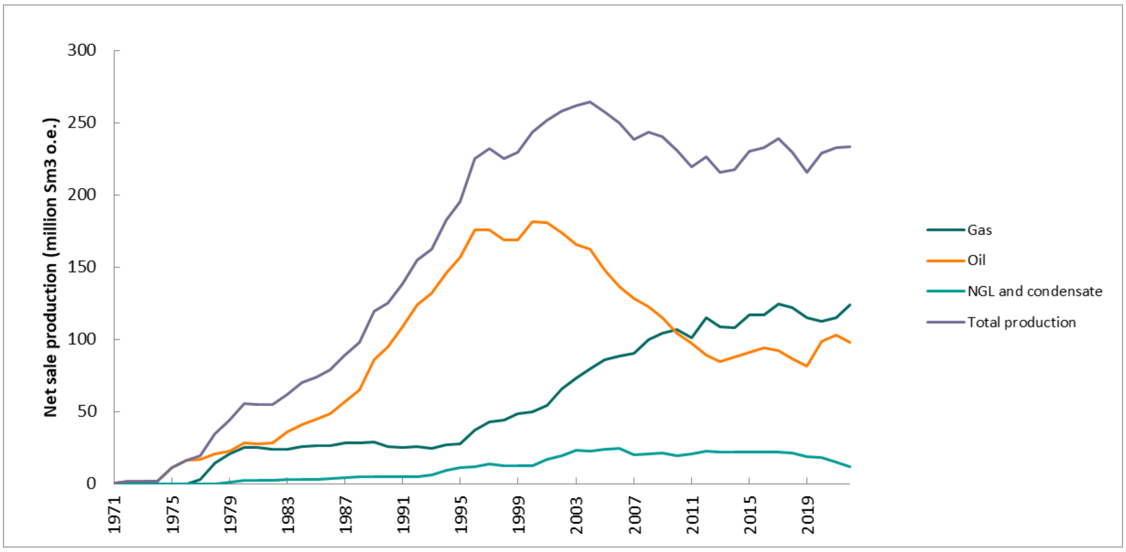


Figure 3.17: Net sale production of oil, gas and NGL and condensate. Million Sm³ oil equivalents. Source: Norwegian Offshore Directorate.

Figure 3*.18* shows the number of exploration wellbores on the Norwegian continental shelf in the period 1990-2022 (by year entered/spudded). 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 (by year entered/spudded) are shown in *Figure 3.19.*

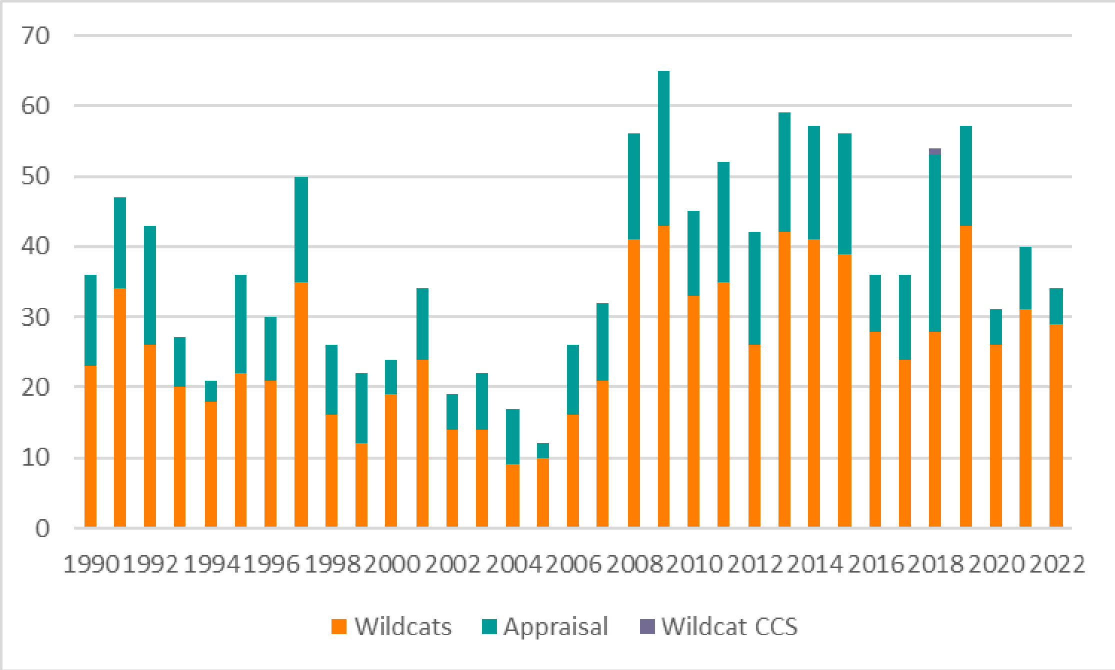


Figure 3.18: Exploration wellbores. Number of wildcats, appraisal wells and wildcats for CCS. Source: Norwegian Offshore Directorate.

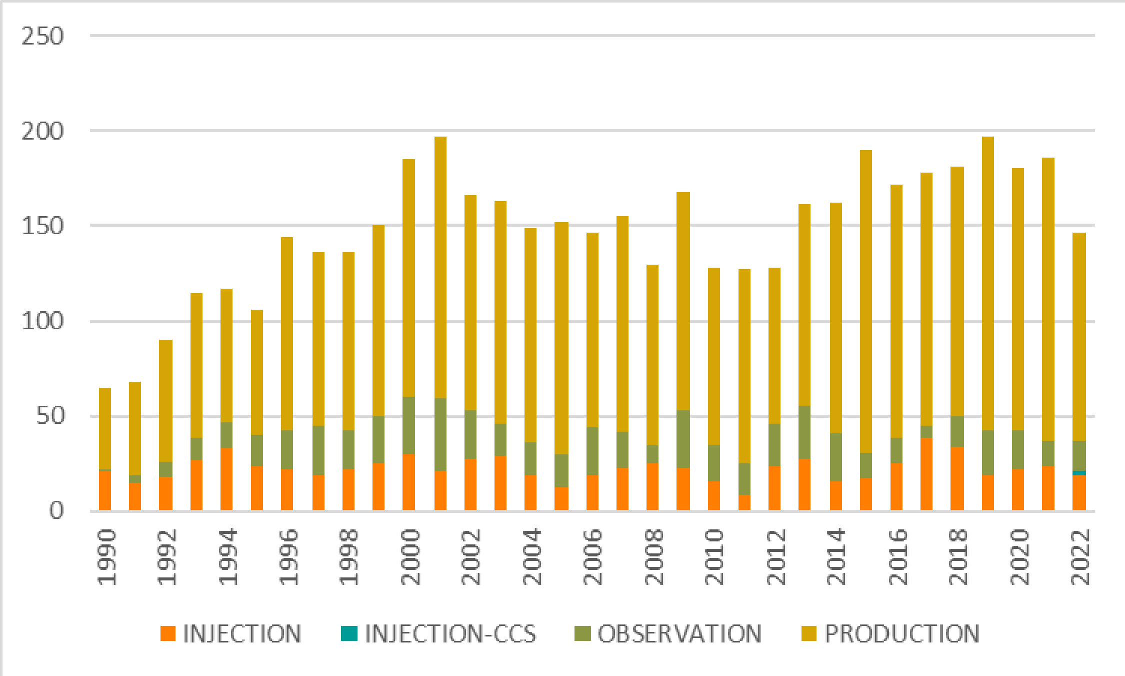


Figure 3.19: Development wellbores. Number of production, observation, and injection wells, as well as injection wells for CCS. Source: Norwegian petroleum directorate.

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. Venting and other emissions connected to CCS are reported in 1C, see Section 3.4.

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".

3.3.2.1.1 Fugitive emissions 1990-2022

Fugitive emissions from oil, natural gas and venting and flaring, accounted for 4% of the total GHG emissions in Norway in 2022, and 6% of the total GHG emissions in the energy sector.

Figure 3.20 shows the trend in fugitive emissions from oil and gas production, venting and flaring, and *Figure 3.21* shows the relative change in emissions from the same sources. The total sector emissions decreased by 31% from 1990 to 2022 but remained unchanged between 2021 and 2022.

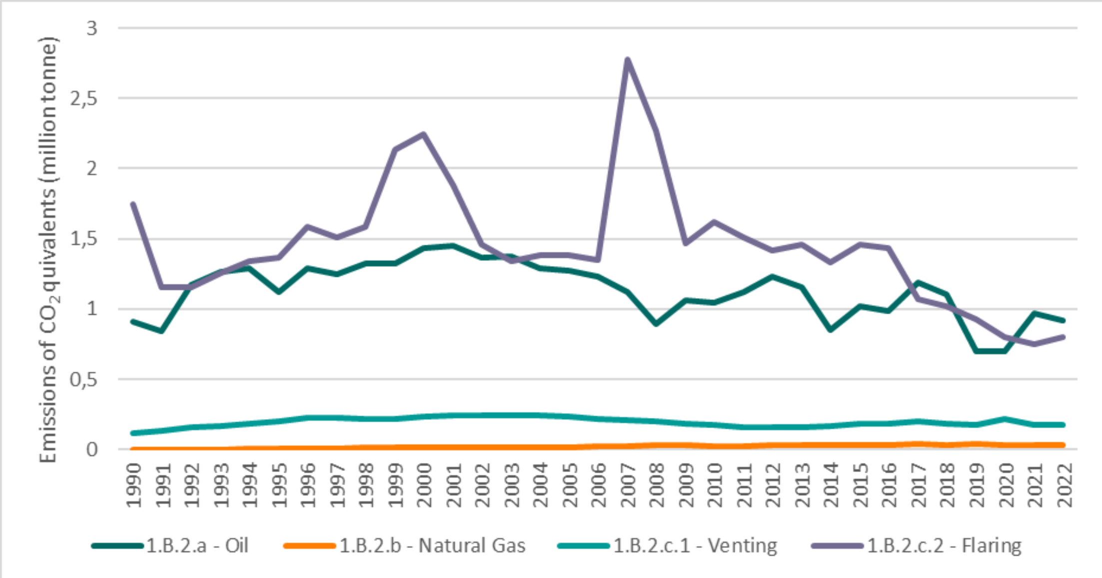


Figure 3.20: 1.B.2 Fugitive emissions from oil and gas related activities. Million tonne CO_2 equivalents. Source: Statistics Norway/Norwegian Environment Agency.

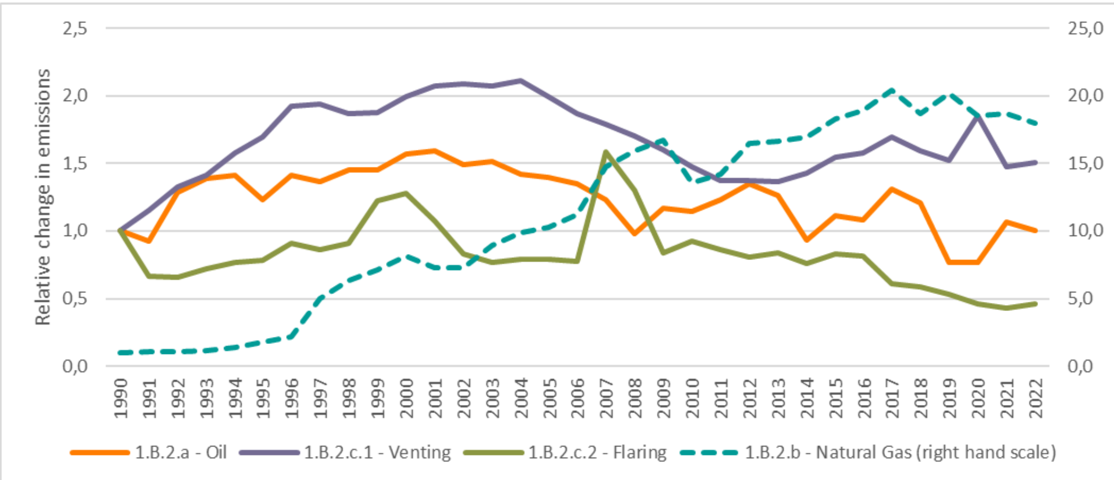


Figure 3.21: Relative change in 1.B.2 Fugitive emissions in CO_2 equivalents from oil and gas related activities. 1990=1. Source: Statistics Norway/Norwegian Environment Agency.

The fugitive emissions from oil and gas activities, excluding 1.B.2.a.4 (see description of this source below), decreased by 45% between 1990 and 2022, while the total production of oil, gas and NGL and condensate increased by 87%. 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 CH_4 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 3.20*) were due to start-up problems at an LNG plant. More information about flaring offshore is given in chapter 3.3.6.

Emissions from 1.B.2.a.3 transport, which are mainly indirect CO_2 emissions of NMVOC and CH_4 from storage and loading of crude oil offshore and onshore, are reduced substantially due to implemented measures. The reduction has been counteracted by increased emissions from catalytic cracking in 1.B.2.a.4. Catalyst regeneration (coke burn-off) in a catalytic cracker unit at one refinery 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 1B2a in 2019 and 2020 are mainly caused by lower activity as the catalytic cracker was replaced.

Emissions from natural gas distribution increased by orders of magnitude between 1990 and 2009 due to increased domestic gas distribution but has since levelled off. In 2022 the emissions were about 20 kilotonnes CO_2 equivalents.

3.3.2.1.2 Overall description of methodology for fugitive emissions from fuels

Table 3-32 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_2, CH_4, N_2O and NMVOC. The table shows if the EF and/or AD used in the calculations 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 3.3.6 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.

Table 3-31 shows the shares of total CO_2, CH_4 and N_2O emissions in the sector that is based on reported emissions and estimates by the Statistics Norway in 2022. It can be seen that about 90% of the CH_4 and CO_2 emissions in the sector, included coal mining, are based on reports from the plants, mainly offshore installations. N_2O is based on estimates performed by Statistics Norway.

Table 3-31: Shares of total CO_2, CH_4 and N_2O emissions based on reported emissions and estimates

	CO_2		CH_4		N_2O	
	Estimated	Reported	Estimated	Reported	Estimated	Reported
1B Fugitive emissions from fuels	7%	93%	22%	78%	100%	0%
1.B.1.a Coal Mining	100%	0%	100%	0%		0%
1.B.2.a Oil	8%	92%	0%	100%		0%
1.B.2.b Natural gas	100%	0%	63%	37%		0%
1.B.2.c Venting and flaring	5%	95%	0%	100%	100%	0%

Source: Statistics Norway/Norwegian Environment Agency

<u>Sector 1.B.2.a Oil:</u>

- CO_2*: 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_2 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_2.
- CH_4*:* 100% is based on *reports* from refineries and oil and gas installations.

<u>1.B.2.b Natural gas:</u>

- CO_2: 100% is *estimated* and is indirect CO_2 based on mostly reported CO_2 emissions from gas terminals.
- CH_4: 37% of the emissions is based on *reported* emissions from gas terminals.

<u>1.B.2.c Venting and flaring:</u>

- CO_2: 95% of the emissions are based on *reports* mostly from the oil and gas installations.
- CH_4: 100% of the emissions are *reported* emissions from the oil and gas installations.

Table 3-32: Fugitive emissions from oil and natural gas. Emission sources, compounds, methods, emission factors and activity data included in the Norwegian GHG Inventory

Fugitive emissions from fuels	CO_2	CH_4	N_2O	NMVOC	Method	Emission factor	Activity data
1.B.2.a Oil							
i. Exploration	IE	R	NO	R	Tier II	CS	PS
ii. Production	IE	R	NA	R	Tier II	CS	PS

iii. Transport	IE	R/E	NA	R/E	Tier II	CS	PS
iv. Refining/Storage	R/E	R	NA	R	Tier II	CS	PS
v. Distribution of oil products	E	NA	NA	R/E	Tier II	C/CS	CS/PS
vi. Other	IE	NA	NA	NO			
1.B.2.b Natural gas							
i. Exploration	IE	IE	NA	IE	Tier II	CS	PS
ii. Production	IE	R	NA	R	Tier II	CS	PS
iii. Processing	IE	IE	NA	IE	Tier II	CS	PS
iv. Transmission and storage	IE	IE	NA	IE	Tier II	CS	PS
v. Distribution	IE	E	NA	IE	Tier II	OTH	CS/PS
vi. Other	E	R	NA	R	Tier II	CS	PS
1.B.2.c							
Venting							
i. Oil	IE	R	NA	R	Tier II	CS/PS	PS
ii. Gas	IE	R	NA	R	Tier II	CS/PS	PS
iii. Combined	NO	NO	NA	R/E	Tier II	CS/PS	PS
Flaring							
i. Oil (well testing)	R/E	E	E	R/E	Tier II	CS	PS
ii. Gas							
- Gas and oil fields	R/E	R/E	E	R/E	Tier II	CS	PS
- Gas terminals	R	R	E	R/E	Tier I	CS	CS
- Refineries	R	R	R/E	E	Tier I	CS	CS
iii. Combined	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.*

Indirect emissions of CO_2 from emissions of CH_4 and NMVOC are reported separately in CRF Table 6.

3.3.2.1.3 QA/QC

The requirements in the "Management Regulation" 34c (see above) text above refers to QC within the reporting company as well as QC by Offshore Norge (the employer and industry organization for companies with activities related with the Norwegian continental shelf).

The annual reports from the operators are quality checked by NEA. This includes for instance crosschecking of reported CO_2 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.

Statistics Norway gathers activity data used in the calculation from the Norwegian Offshore 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 Offshore Directorate and time series are checked.

3.3.2.2 Diffuse emissions and venting from oil and gas exploration and production

This section describes fugitive emissions reported from upstream oil and gas activities, and how these emissions are allocated to one of the six source categories 1B2ai (Oil exploration diffuse emissions), 1B2aii (Oil production diffuse emissions), 1B2bi (Natural gas exploration diffuse emissions), 1B2bii (Natural gas production diffuse emissions), 1B2c(Venting)i (Oil) and 1B2c(Venting)ii (Gas). No venting emissions takes place from exploration activities.
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_4 and NMVOC. Venting of CH_4 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.

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. Note that Table 3-33 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).

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 3.3.2.2.1.

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). The reporting is mandatory and regulated by the Norwegian Pollution Control Act and associated official guidelines (M-107) issued by NEA.

The source specific quantification and reporting of emissions, provides a firm basis for assessment of measures for emission reductions.

3.3.2.2.1 Methodological issues

Emissions of CH_4 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_2 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 reports from 2017 onwards. For the years 1990-2016 recalculated emission estimates are reported. 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. The new method for estimation and reporting of emissions is described below.

Methodology 2017-present

Fugitive emissions of methane and nmVOC are calculated using a so-called "bottom-up" method. The annual emissions for *venting* and *diffuse emissions* from each petroleum facility is quantified (calculated) using methods for each individual source, see Table 3-33 and

Table 3-34. Table 3-33 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).

Based on the outcome of the above-mentioned study, dedicated methodologies were recommended for the individual emission sources (and sub-sources), see Table 3-33. 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 3-33.

Table 3-33: 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
80.2	Flare gas that does not burn	Non-flammable flare gas	FSM	Established by each operator
80.3	Flare gas that does not burn	Inert gas flushed open flare	GM	Flare gas metering
90.1	Leaks in the process	Larger gas leaks	GM	Emission rate, duration, volume (current practice)
90.2	Leaks in the process	Small gas leaks	GM	OGI "leak/no leak" method
100.1	Purge and blanket gas	Purge and blanket gas	GM	Purge/blanket gas metering/flow rate determination
110.1	Gas analysers and test stations	Gas analysers and test stations	GM	Slipstream flowrate
120.1	Drilling	Drilling	GM	Emission factor per completed wellbore
130.1	Storage tanks for crude oil at FPSOs	Gas freeing in connection with tank inspection	GM	Storage tank volume
130.2	Storage tanks for crude oil at FPSOs	Abnormal operating situation	FSM	Established by each operator
140.1	Gas freeing of process systems	Gas freeing of process systems	GM	Volume of process plant
900.1	General addition	FPSO	GM	Percentage of other emissions
910.1	General addition	Fixed facilities	GM	Percentage of other emissions

Source: Add Novatech AS (2016c) and Norwegian Oil and Gas (2021)

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 with respect to:

- measurement/sampling
- process simulations / use of special computer programmes
- utilising available registered measurement data
- logging of incidents (for batch emissions)
- supplier data

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 (Offshore Norge 2023)). 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).

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, the number of wellbores serves as AD. See guidelines in (Offshore Norge 2023) and further elaboration in Husdal et al. (2016). Only emissions are reported by the operators.

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^3 produced water through the degassing point and per bar pressure drop from nearest upstream degassing point), see guidelines in Offshore Norge (2023) and further elaboration in Husdal et al. (2016)

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 3-34 and Table 3-35 illustrate the details in the annual reported emissions from the operators. Small discrepancies between CRF data and these tables are due to difference in updating status, etc.

Table 3-34: Venting emissions from offshore oil and gas production in 2022.

Source ID	Main source	Sub source	CH_4 emissions (tonnes)	nmVOC emissions (tonnes)	Emissions of CO_2 equivalents (tonnes)[18]
1.1	Measured emissions	Measured common vent	2406	3315	74049
10.1	Triethyleneglycol (TEG) regeneration	TEG degassing tank	0	0	0
10.2	Triethyleneglycol (TEG) regeneration	TEG regenerator	50	546	2583
10.3	Triethyleneglycol (TEG) regeneration	Stripping gas	230	567	7631
20.1	Monoethyleneglycol (MEG) regeneration	MEG degassing tank	0	0	0
20.2	Monoethyleneglycol (MEG) regeneration	MEG regenerator	3	179	489
20.3	Monoethyleneglycol (MEG) regeneration	Stripping gas	0	163	359
30.1	Amine regeneration	Amine degassing tank	0	0	0
30.2	Amine regeneration	Amine regenerator	0	0	0
40.1	Produced water handling	Produced water degassing tank	181	77	5201
40.2	Produced water handling	Flotation tank / CFU	146	37	4136
40.3	Produced water handling	Flotation gas	0	0	0
40.4	Produced water handling	Discharge caisson	1053	263	29786
50.1	Centrifugal compressor sealant oil	Degassing pots	0	0	0
50.2	Centrifugal compressor sealant oil	Sealing oil retention tank	1	0	35
50.3	Centrifugal compressor sealant oil	Sealing oil storage tank	1	1	29
60.1	Pistonne compressor	Separator chamber	18	21	554
60.2	Pistonne compressor	Crank shaft housing	16	19	486
70.1	Dry compressor seals	Primary seal gas	563	285	16237
70.2	Dry compressor seals	Secondary seal gas	39	11	1104

[18] Emissions of CO_2 equivalents include indirect CO_2 emissions from CH_4 and NMVOC, using conversion factors of 2,75 t CO_2/t CH_4 and 2,2 t CO_2/t NMVOC. The NMVOC conversion factor is a generic factor for indirect CO_2 calculations.

70.3	Dry compressor seals	Leakage of primary seal gas to secondary vent	139	117	4123
80.1	Flare gas that does not burn	Extinguished flare and ignition of flare	633	639	18969
80.2	Flare gas that does not burn	Non-flammable flare gas	210	117	6078
80.3	Flare gas that does not burn	Inert gas flushed open flare	162	144	4803
100.1	Purge and blanket gas	Purge and blanket gas	122	85	3567
110.1	Gas analysers and test stations	Gas analysers and test stations	28	13	806
130.1	Storage tanks for crude oil at FPSOs	Gas freeing in connection with tank inspection	96	51	2768
130.2	Storage tanks for crude oil at FPSOs	Abnormal operating situation	9	73	422
140.1	Gas freeing of process systems	Gas freeing of process systems	12	35	421
Totals			6118	6757	184635

Table 3-35: Diffuse emissions from offshore oil and gas production in 2022.

Source ID	Main source	Sub source	CH_2 emissions (tonnes)	nmVOC emissions (tonnes)	Emissions of CO_2 equivalents (tonnes)
90.1	Leaks in the process	Larger gas leaks	31	23	911
90.2	Leaks in the process	Small gas leaks	309	302	9241
120.1	Drilling	Drilling	39	39	1176
900.1	General addition	FPSO	32	23	940
910.1	General addition	Fixed facilities	56	65	1684
Totals			467	451	13951

As an example, reported information from the Åsgard B facility is shown in Table 3-36. The operator reported methane emissions from all 34 identified sources (ref. Table 3-33). 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 Offshore Norge (2023) and further elaborated in (Husdal et al. 2016).

Using source 70.1 (ref.

Table 3-34) as an example, the operator at Åsgard B reports that the methodology used is "Indirect measurements". Offshore Norge (2023) 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". Offshore Norge (2023) recommends a Facility-specific method for this emission source. Husdal et al. (2016), chapter 4.4.5 provides the justification for the recommendation.

Table 3-36: Diffuse emissions from Åsgard B in 2021.

Year	Facility	Main source	Sub source	Methodology	Source ID	CH_4 emissions (tonnes)	nmVOC emissions (tonnes)
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	Triethylene glycol (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 compresso	Sealing oil storage tank	Not present	50.3	0	0

		r sealant oil					
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	Triethylene glycol (TEG) regeneration	Stripping gas	Recycled	10.3	0	0
2021	ÅSGARD B	Triethylene glycol (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
		Total				859	923

The allocation of reported emissions into the source categories for diffuse emissions and venting relevant for upstream oil and gas activities is described below.

Emissions from sources listed in

Table 3-34 are categorised as "Venting emissions" and allocated to CRF 1B2c(Venting)i (Oil) or 1B2c(Venting)ii (Gas), depending on whether the installation from which they occur is classified as an "oil" or "gas" installation. (See below).

Similarly, emissions from sources listed in Table 3-35 are categorised as "Diffuse emissions" and allocated to CRF 1B2b2 or 1B2a2, depending on the classification of the installation. Additionally, the emissions may be allocated to 1B2a1 if the reported activity from which the emissions occur is "Exploration". All exploration activities are categorised as "Oil Exploration" (1B2a1).

Emissions are reported on facility level. Most petroleum facilities on the Norwegian continental shelf handles a combination of oil and gas, and it is therefore challenging to truly differentiate between oil production and gas production as sources for the emissions. We have used the following method:

1. Facilities with any reported production of oil in a given year, are categorised as "Oil" for that year. (Regardless of whether the facility also produces gas or condensate.) Facilities with any reported production of gas or condensate, but no production of oil, are categorised as "Gas".
2. Some facilities have no reported production in any year. If such a facility is associated with a field with any reported production of oil, it is categorized as "oil". If the associated field has no reported production of oil, but does report production of gas or condensate, the facility is categorized as "Gas".
3. The very few facilities remaining are categorized as "Oil".

Diffuse emissions from "Oil" installations are allocated to source category 1B2a2, and venting emissions to source category 1B2c(Venting)i. Diffuse emissions from "Gas" installation are allocated to source category 1B2b2, while venting emissions are allocated to 1B2c(Venting)ii.

Table 3-37: Allocation of reported emissions.

Activity	Type of installation	Type of emission	Source category
Exploration	Oil	Diffuse emissions	1B2a1
Exploration	Oil	Venting	1B2c(Venting)i*
Production	Oil	Diffuse emissions	1B2a2
Exploration	Oil	Diffuse emissions	1B2a1
Production	Gas	Diffuse emissions	1B2b2
Production	Gas	Venting	1B2c(Venting)ii
Production	Oil	Venting	1B2c(Venting)i

<u>1990-2016 time series</u>

The methods for calculating the timeseries 1990-2016 for venting and diffuse emissions are described below.

Emissions are calculated by multiplying relevant EFs by activity data. EFs for all source categories are based on IEF for the years 2017-2021.

1B2a1 (Diffuse emissions from oil exploration):

EF_{1B2a1} *= Sum of emissions in 1B2a1 2017-2021 / Sum of number of exploration wellbores 2017-2021*

1B2b2 (Diffuse emissions from gas production on gas installations):

EF_{1B2b2} *= Sum of emissions in 1B2b2 in 2017-2021 / Sum of gas production on gas facilities (in* Sm^3*) 2017-2021*

1B2c(Venting)ii (Venting emissions from gas production on gas installations):

$EF_{1B2c(Venting)ii}$ *= Sum of emissions in 1B2c(Venting)ii in 2017-2021/*
Sum of gas production on gas facilities (in Sm^3*) 2017-2021*

The method for allocating emissions between oil or gas production, relies on categorising facilities as either oil or gas installations (see above). This entails that emissions from gas production on oil installations are included in "Oil emissions" (In source categories 1B2a2 or 1B2c(Venting)i). We assume that emission factors for gas production on gas facilities are also applicable for gas production on oil facilities.

1B2a2 (Diffuse emissions from gas production on oil installations):

$EF_{1B2a2(gas\ production)}$ *=*EF_{1B2b2} *= Sum of emissions in 1B2b2 in 2017-2021 / Sum of gas production on gas facilities (in* Sm^3*) 2017-2021*

1B2c(Venting)i (Venting emissions from gas production on oil installations):

$EF_{1B2c(Venting)i(gas\ production)}$ *=* $EF_{1B2c(Venting)ii}$ *= Sum of emissions in 1B2c(Venting)ii in 2017-2021/*
Sum of gas production on gas facilities (in Sm^3*) 2017-2021*

Additionally, EFs for oil production on oil facilities need to be derived. This is done by calculating the emissions from gas production on an oil facility using the EFs for gas, and then subtracting these emissions from the total emissions from the facility. EF for oil production on the facility is then derived as remaining emissions divided by oil production on the facility, as described in the two equations below.

1B2a2 (Diffuse emissions from oil production on oil facilities):

*$EF_{1B2a2(oil\ production)}$ = (Sum of emissions in 1B2a2 2017-2021 – EF_{1B2b2}*sum of gas production on oil facilities) / Sum of oil production on oil facilities (in* Sm^3*) 2017-2021*

1B2c(Venting)i (Venting emissions from oil production on oil facilities):
*$EF_{1B2c(Venting)i(oil\ production)}$= (Sum of emissions in 1B2c(Venting)i 2017-2021 – $EF_{1B2c(Venting)ii}$*sum of gas production on oil facilities) / Sum of oil production on oil facilities (in* Sm^3*) 2017-2021*

The necessary activity data for production on facility level are available only for the period 2000-2021. These AD are expressed in terms of gross production Sm^3. For period 1990-1999 only the yearly net production data (for the Norwegian continental shelf) are available. We have therefore decided to derive the yearly gross production for 1990-1999 from the yearly net production for 1990-1999, based on their relationship in the period 2000-2021 during which we have data on both.

Yearly gross oil production:
A strong linear relation has been found to exist between the yearly gross production and net production of oil between 2000 and 2021. A simple linear regression is therefore deployed:
Yearly gross oil production = a * yearly net oil production + b

Yearly gross gas production:
Linear regression yields gross gas productions which are relatively invariable and independent of net productions for period 1990-1999. This seems unlikely since the total net production of oil and gas has risen significantly in this period. Given the substantial production increase and rapidly changing circumstances, we have chosen to derive gross gas productions as a fraction of net oil + gas productions for period 1990-1999 and selected 2000 as the base year for calculation. So for 1990-1999, we have:
Yearly gross gas production = $\left(\frac{gross\ gas\ production}{net\ oil+gas\ production}\right)_{year\ 2000}$ * yearly net (oil + gas) production

Yearly gross gas production on gas facilities:
The yearly gross gas productions need to be split between productions on oil facilities and gas facilities. This is achieved by a simple linear regression since the ratio between gross gas production on gas facilities and total gross gas production remains relatively stable in period 2000-2021. For 1990-1999 we therefore have:
Yearly gross gas production on gas facilities = c * yearly gross gas production + d

The method now used to extrapolate emissions from 2016 back to 1990 does not consider improvements in technology during the period. We have assumed same emissions per unit produced oil equivalent for the whole timeseries. technology improvements will have led to reduced emissions and thus there is a risk that the emissions early in the timeseries are underestimated. Due to lack of data, we have not been able to adjust the emissions the first years of the inventory.

Verification

Implied emission factors from the reported data have been compared to the Tier 1 emission factors given in IPCC (2006), as well as with factors given in IPCC (2019), where possible (Table 3-38). Compared to IPCC 2006, the Norwegian emission factors are lower for the source category 1B2a2 (diffuse emissions from oil production), but higher for 1B2b2 (Diffuse emissions from gas production) and 1B2c(Venting)i (Venting emissions from gas production). Compared to IPCC 2019 refinement, all Norwegian emission factors are lower.

Table 3-38: Comparison of emission factors.

Source category	IEF Norway 2017-2021	EF Tier 1 IPCC 2006	EF Tier 1 IPCC 2019	IEF Norway 2017-2021	EF Tier 1 IPCC 2006	EF Tier 1 IPCC 2019	Units
	CH_4			nmVOC			
1B2a1	0,0307	-	-	0,0307	-	-	Tonnes per well
1B2b1	-	-	-	-	-	-	
1B2b2	0,00128	0,38	0,676	0,00137	0,091	0,161	Tonnes per mill Sm^3 gas produced on gas installations
1B2a2	0,00346	0,00059	0,492	0,00328	0,00074	0,212	Tonnes per thousand Sm^3 oil produced
1B2c(Venting)i	0,0372	0,72	1,96	0,0413	0,43	0,848	Tonnes per thousand Sm^3 oil produced
1B2c(Venting)ii	0,0242	-	2,26	0,0302	-	0,539	Tonnes per mill Sm^3 gas produced on gas installations

Comparisons of reported and estimated CH_4 and nmVOC venting/diffuse emissions to estimates using IPCC 2006 default factors are shown in Figure 3.22 and Figure 3.23. Emissions from exploration have not been compared, as default EFs either do not exist, or are not given at the relevant source level (IPCC 2006 gives EFs for venting and flaring combined). Also, we have not been able to compare emissions from venting in oil production with default EFs from IPCC 2006. This is because even though IPCC 2006 provides EFs for venting from oil production, it does not provide such for gas production.

This leaves us unable to estimate emissions from gas production on the combined oil and gas production fields under 1B2c(Venting)i using default factors.

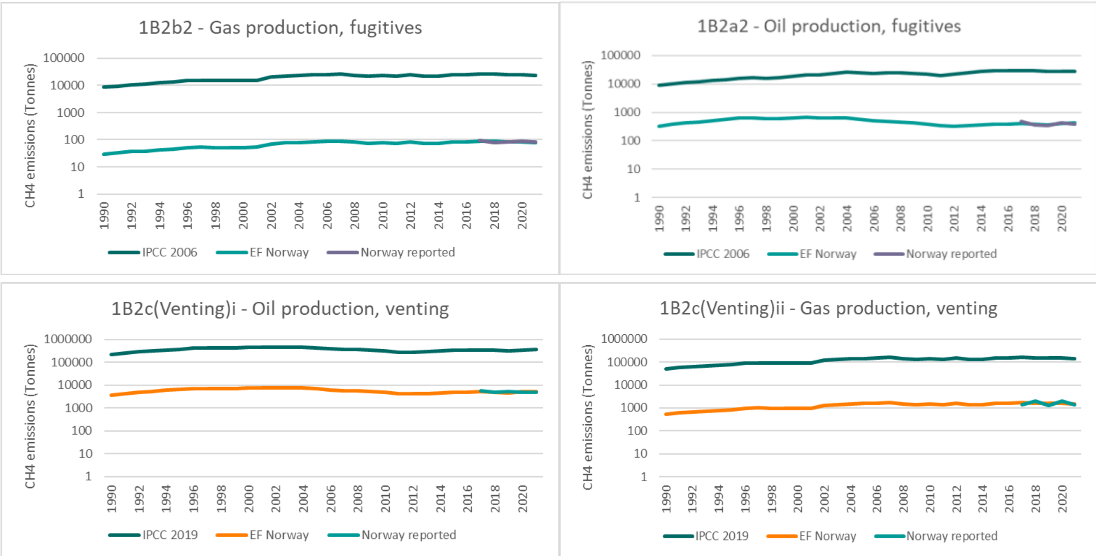


Figure 3.22: CH_4 emissions IPCC default factors and country specific emission factors, respectively.

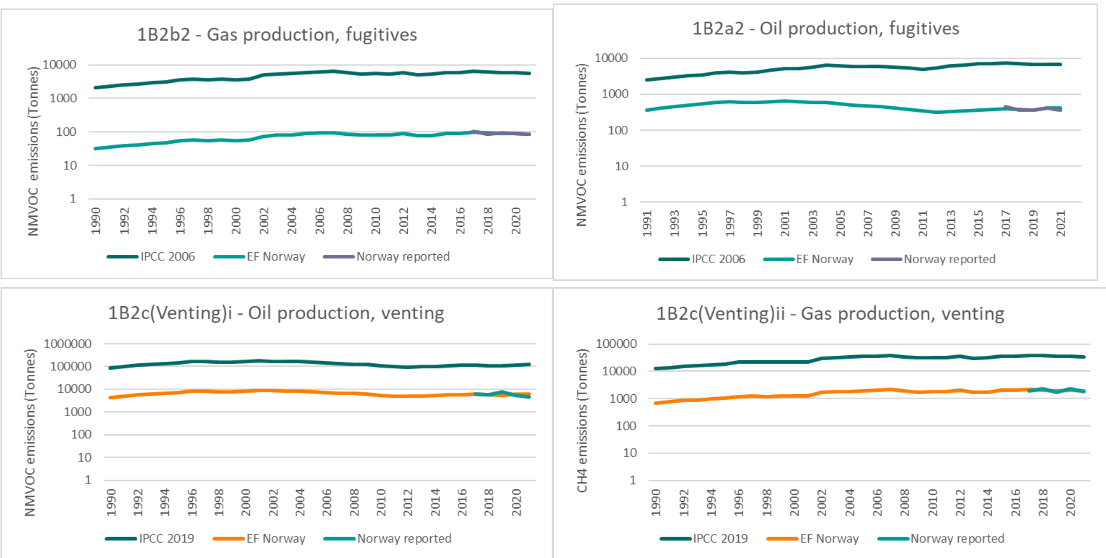


Figure 3.23: NMVOC emissions using IPCC default factors and country specific emission factors, respectively.

The comparison shows that emissions are low relative to the estimates using IPCC default factors. The CH_4 reported emissions are 0,3-3,9% of emission values using IPCC default factors. For nmVOC reported emissions are 1,5-15,4% of values found using IPCC default factors.

Information on the background for the low CH_4 and nmVOC emissions (regulatory regimes, reporting regimes) may be found in section 3.3.2.2. The venting rate is low due to strict security regulations. To minimize emissions from venting, several technical measures have been implemented on the offshore production facilities.

Measures implemented on the shelf include operational optimization, recovery of waste gases by returning it back to the process or to flare. These measures are further described in (Add Novatech AS 2016a) and (Geir Husdal et al. 2016). Recovery of waste gases is BAT for new field development projects and is re-evaluated when modifications on existing field. The BAT regulation in Norway also includes requirements on implementing leak detection and repair (LDAR) programs to reduce fugitive emissions.

3.3.3 Fugitive Emissions from Oil, 1.B.2.a (Key category for CO_2 and CH_4)

3.3.3.1 Description

This section describes emissions from transport (loading and storage of crude oil), refining of oil and distribution of gasoline. For emissions from exploration (1B2a1) and production (1B2a2), see section 3.3.2.

<u>Transport of crude oil – 1B2a3</u>

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_4 and indirect emissions of CO_2 from oxidized NMVOC and CH_4. 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.

Refining/storage – 1B2a4
Non-combustion emissions from Norway's oil refineries include CO_2, CH_4 and NMVOC. It is important to have in mind that the source category 1.B.2.a.iv also includes CO_2 emissions from catalyst regeneration (coke burn off) at the catalytic cracker at one refinery, see section 3.3.2.1.1.

Distribution – 1B2a5
Gasoline distribution causes emissions of NMVOC, which lead to indirect CO_2 emissions. These emissions are reported in table 6. However, activity data are still reported under 1B2a5.

Fugitive emissions from oil (1B2a) is a key category for CO_2, and CH_4 both level in 1990 and 2002 and trend, following approach 2.

3.3.3.2 Methodological issues

Transport – 1.B.2.a.iii
The general method for calculating emissions of CH_4 and NMVOC from offshore 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_4 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. 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_4 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 are reported from each field operator into the database Footprint. The database is operated by Offshore Norge (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.

Norway considers the method for calculating the CH_4 and NMVOC emissions from loading and storage of crude oil offshore is consistent for the period 1990-2022.

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_2, CH_4 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_2 emissions from the oxidation of CH_4 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_2, CH_4 and NMVOC included in the inventory are reported by the refineries to the Norwegian Environment Agency. The direct CO_2 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 are therefore regarded being of high quality.

Statistics Norway calculates the indirect CO_2 from oxidized CH_4 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.

3.3.3.3 Activity data

Transport – 1.B.2.a.iii

The amount of oil buoy loaded and stored on vessels offshore is reported by the field operators into the Footprint database to the Norwegian Environment Agency (NEA). 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 Offshore Directorate. The data from each field are reported monthly by the field operators to the Norwegian Offshore Directorate.

The amount of oil loaded at onshore oil terminals is also reported annually to the Norwegian Environment Agency.

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.

3.3.3.4 Emission factors

Transport – 1B2a3

From 1990 to 2002 emission factors used in the calculation of CH_4 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 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. The emission factors used by the field operators in their calculations is reported to the Norwegian Environment Agency The emission factors are reported by the field operators into the database Footprint.

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_4 content of the VOC evaporated is also measured so that total emissions of VOC are split between CH_4 and NMVOC.

Loading onshore: 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_2 emissions from the catalytic cracker during catalyst regeneration are calculated as described above under Methodological issues. The CO_2 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) and FLIR.

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.

3.3.3.5 Uncertainty assessment 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 ± 40% and in the activity data ± 3%.

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

3.3.3.6 Source-specific QA/QC and verification

See annex 5a on QA/QC of point 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. 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.

3.3.3.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.3.3.8 Category-specific planned improvements

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

3.3.4 Fugitive Emissions from Natural Gas, 1.B.2.b

3.3.4.1 Description

This chapter describes fugitive emissions of CH_4 and NMVOC and indirect emissions of CO_2 from the two gas terminals and emissions from distribution of natural gas. For 1.B.2.b.i Exploration and ii Production see section 3.3.2.2.

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 both transmission, processing, distribution and storage within the main extraction/export system is reported in 1.B.2.b vi Other. All emissions from the domestic system are 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".

3.3.4.2 Methodological issues

Other (Gas terminals) – 1B2b6

Fugitive emissions of CH_4 and NMVOC from gas terminals are reported annually to the Norwegian Environment Agency.

Emissions from gas terminals includes CH_4 and NMVOC and hence indirect CO_2. 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 – 1B2b5

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_4 are reported in 1.B.2.b.v. CO_2 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_2 in the combustion emissions in 1A. This applies to both direct emissions of CO_2 and indirect CO_2 emissions from CH_4 leakage. Direct emissions of CO_2 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.

3.3.4.3 Activity data

Other (Gas terminals) – 1B2b6

Activity data are sampled through the terminals' measuring and maintenance program, which purpose is to reduce leakage.

Gas distribution – 1B2b5

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, whose emissions from transport is included in 1.B.2.b.vi *Other*
- Consumption for methanol production, whose 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).

3.3.4.4 Emission factors

Other (Gas terminals) – 1B2b6

Reported emissions are used.

Gas distribution – 1B2b5

Emission factors from IPCC (2006) are used for the emission estimates, as shown in Table 3-39. 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 3-39: Emission factors for gas distribution

Category	Subcategory	Emission source	Value	Selected value	Uncertainty
Gas Transmission and Storage	Transmission	Fugitives	6.6 E-05 – 4.8 E-04	2.73 E-04	±100%
		Venting	4.4 E-05 - 3.2 E-04	1.82 E-04	±75%
	Storage	All	2.5 E-05	2.5 E-05	-20 - 500%
Gas Distribution	All	All	1.1 E-03	1.1 E-03	-20 - 500%

Source: IPCC (2006), vol 2 Energy, table 4.2.4

3.3.4.5 Uncertainty assessment 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 ± 3%.

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

3.3.4.6 Source-specific QA/QC and verification

See annex 5a on QA/QC of point sources.

3.3.4.7 Category-specific recalculations

Reallocation: Indirect emissions of CO_2 from emissions of CH_4 and NMVOC are now reported separately in CRF Table 6.

3.3.4.8 Category-specific planned improvements

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

3.3.5 Fugitive Emissions from Venting, 1.B.2.c Venting (Key category for CO_2 and CH_4)

3.3.5.1 Description

This chapter contains some information on venting from upstream oil and gas activities, however, most information is to be found in chapter 3.3.2.

CO_2 and CH_4 from venting and flaring is according to approach 2 a key category with respect to level in 1990 and 2022 and trend.

3.3.5.2 Methodological issues

See chapter 3.3.2

3.3.5.3 Activity data

See chapter 3.3.2

3.3.5.4 Emission factors

See chapter 3.3.2

3.3.5.5 Uncertainty assessment and time-series consistency

The uncertainty in CH_4 and NMVOC emissions from venting and diffuse emissions and, hence, in the indirect emissions of CO_2, is much higher than for flaring.

All uncertainty estimates for this source are given in Annex 2.

3.3.5.6 Source-specific QA/QC and verification
See annex 5a on QA/QC of point sources.

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.

3.3.5.7 Category-specific recalculations
Reallocation: Indirect emissions of CO_2 from emissions of CH_4 and NMVOC are now reported separately in CRF Table 6.

3.3.5.8 Category-specific planned improvements
There are no planned activities this year that will improve the data quality or the documentation for this source category.

3.3.6 Fugitive Emissions from Flaring, 1.B.2.c Flaring (Key category for CO_2 and CH_4)

3.3.6.1 Description
The sector 1.B.2.c Flaring includes emissions from flaring of gas offshore during extraction and production, at gas terminals and at refineries.

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 Environment Agency.

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 small compared to many other countries.

The CO_2 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*.

In 2022, CO_2 equivalents emissions from flaring offshore contributed with 2% to the total GHG emissions in Norway. The emissions were 54% lower in 2022 than in 1990, whereas the oil and gas production was 86% higher (*Figure 3.24*). The reduction in emissions from flaring is partly explained by the introduction of tax on gas flared offshore 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 flaring technical measures have been implemented. The leap in emissions from offshore flaring in 1999-2001 occurred because several oil/gas fields came into production in that period.

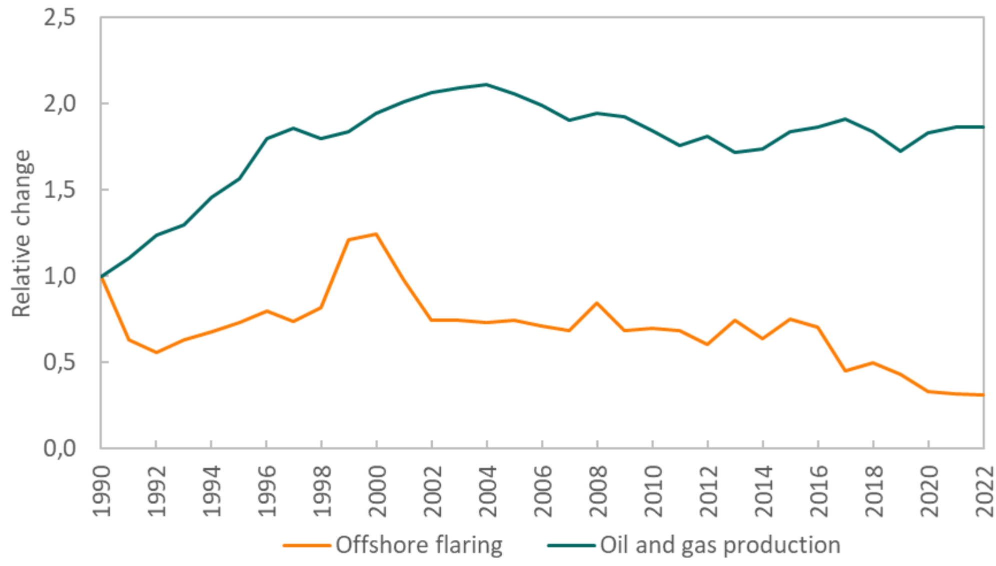


Figure 3.24: Relative change in CO_2 emissions from flaring offshore and total production of oil and gas (including NGL and condensate). 1990=1. Source: Statistics Norway/Norwegian Environment Agency

Venting and flaring is according to Approach 2 a key category with respect to CO_2 for both level in 1990 and 2022 and trend, and for CH_4 with respect to level in 1990 and 2022.

3.3.6.2 Methodological issues

<u>Flaring of gas offshore - CO_2</u>

The general method for calculating CO_2 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.

The EU ETS data are reported annually to the Norwegian Environment Agency. From 2008, emissions of CO_2 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_2 per Sm^3 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.

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 section 3.3.6.4 for information about the emission factors that are used.

We consider that the method is consistent for all years.

Flaring of gas offshore - CH_4 and N_2O

Estimated emissions of CH_4 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 Environment Agency. N_2O emissions from flaring is estimated by Statistics Norway for all years.

Well testing

Emissions of CH_4 and N_2O from flaring of oil in well testing is estimated for all years by Statistics Norway based on the amounts tested reported annually by the field operators to the Norwegian Environment Agency. The same emission factors are used for the whole period. CO_2 emissions from well testing is based on the plants annual report.

Gas terminals

Emissions of CO_2 from flaring are reported from the gas terminals.

Oil refineries

The refineries report annually CO_2 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 section 3.2.4.2 .

3.3.6.3 Activity data

Amounts of gas flared at offshore oil and gas installations are reported monthly by the operators to the Norwegian Offshore Directorate. The amount of gas for 1990-99 are from the Norwegian Offshore Directorate and from the Footprint database for 2000 and onwards.

Amounts of gas flared at the gas terminals are reported to 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 was confirmed in 2003.

3.3.6.4 Emission factors

Flaring offshore – CO_2

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_2. If no flare specific factor is used the default emissions factor is 3.73 kg CO_2 per Sm^3. 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. Therefore, since 2013, flare specific factors have been developed 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 a field specific emission factor is estimated based on the flares with measured data. For 2013, an average emissions factor of 2.637 kg CO_2 per Sm^3 was calculated for all flares at all fields with measurements data.

For the years 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.

For the years after 2007 the EU ETS contains information 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 section 3.3.6.2.

Table 3-40 presents the average EF for flaring offshore for the period 1990-2022.

3.3.6.4.1 Gas terminals

In

Table 3-40, the CO_2 emission factors for flaring at one gas terminal are shown. The CO_2 emissions from flaring at that gas terminal were 30 kilotonnes in 2022.

Table 3-40: Emission factors for flaring of natural gas at offshore oil and gas facilities and one gas terminal onshore.

	Average emission factor for flaring at one gas terminal	Average emission factor for flaring offshore
	tonne CO_2 /tonne natural gas	kg CO_2/Sm^3 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	2.34
1998	2.7	2.34
1999	2.7	2.46
2000	2.7	2.48
2001	2.7	2.37
2002	2.7	2.47
2003	2.7	2.41
2004	2.7	2.45
2005	2.7	2.44
2006	2.69	2.43
2007	2.67	2.43
2008	2.67	3.67
2009	2.67	3.35
2010	2.65	3.18
2011	2.76	3.09
2012	2.75	2.89
2013	2.62	3.17
2014	2.59	2.98
2015	2.53	3.16
2016	2.59	3.01
2017	2.54	3.02
2018	2.65	2.91
2019	2.65	3.02
2020	2.63	2.96
2021	2.72	2.96
2022	2.67	3.03

Source: Norwegian Environment Agency/Norwegian Offshore Directorate/Statistics Norway

3.3.6.4.2 Well testing

Emission factors used in the calculations for well testing are shown in Table 3-41.

Table 3-41: Emission factors for flaring in connection with well testing

Compounds (unit)	Unit/tonne flared oil	unit/kSm³ flared natural gas
CO_2 (tonnes)	3.17	2.72
CH_{42} (tonnes)	Field specific	0.00024
N_2O (tonnes)	Field specific	0.00002
NMVOC (tonnes)	0.0033	0.00006
CO (tonnes)	0.018	0.0015

Source: Offshore Norge (2023)

3.3.6.5 Uncertainty assessment and time-series consistency

The uncertainty in the amount of gas flared is in regarded as being low, ±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_2 emission factor for flaring is ±4.5 (Norwegian Climate and Pollution Agency 2011) and Rypdal and Zhang (2000). All uncertainty estimates for this source are given in Annex 2.

3.3.6.6 Source-specific QA/QC and verification

Statistics Norway and the Norwegian Environment Agency perform internal checks of the reported data for the amount of gas reported as flared from the field operators. Some errors in the time-series are usually found and the field operators are contacted, and changes are made. The quality of the activity data is considered to be high due to a tax on gas flared offshore. The Norwegian Offshore 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.

See annex 5a for QA/QC of point sources.

3.3.6.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

3.3.6.8 Category-specific planned improvements

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

3.4 CO_2 capture and storage at oil and gas production fields, 1C (Key Category for CO_2)

3.4.1 Category description

This chapter describes emissions related to the capture, transport, and storage of CO_2 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 and Askeladd).

Emissions occur primarily from venting of captured CO_2 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_2 reservoirs.

The emissions are reported under 1C CO_2 Transport and storage. The reporting in CRF table 1.C also includes data on total CO_2 injected and stored.

3.4.2 CO_2 capture and storage at the gas-condensate field Sleipner Vest

3.4.2.1 Description

The natural gas in the Sleipner Vest offshore gas-condensate field in the North Sea contains about 9% CO_2. The CO_2 content must be reduced to about 2.5% to meet sales gas specifications. The amount of CO_2 removed has decreased sharply over the last years two years due to depletion of the reservoir. The field and the injection program have been in operation since 1996.

<u>Reservoir</u>

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_2 emissions (introduced in 1991 and extended in 1996). It was therefore decided that the removed CO_2 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_2. 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_2 should be stored under high pressure. Under these conditions CO_2 is liquified and less likely to move upwards than CO_2 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_2 storage because of, among other things, 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 act as an effective barrier to vertical CO_2 leakage, see Figure 3.25.

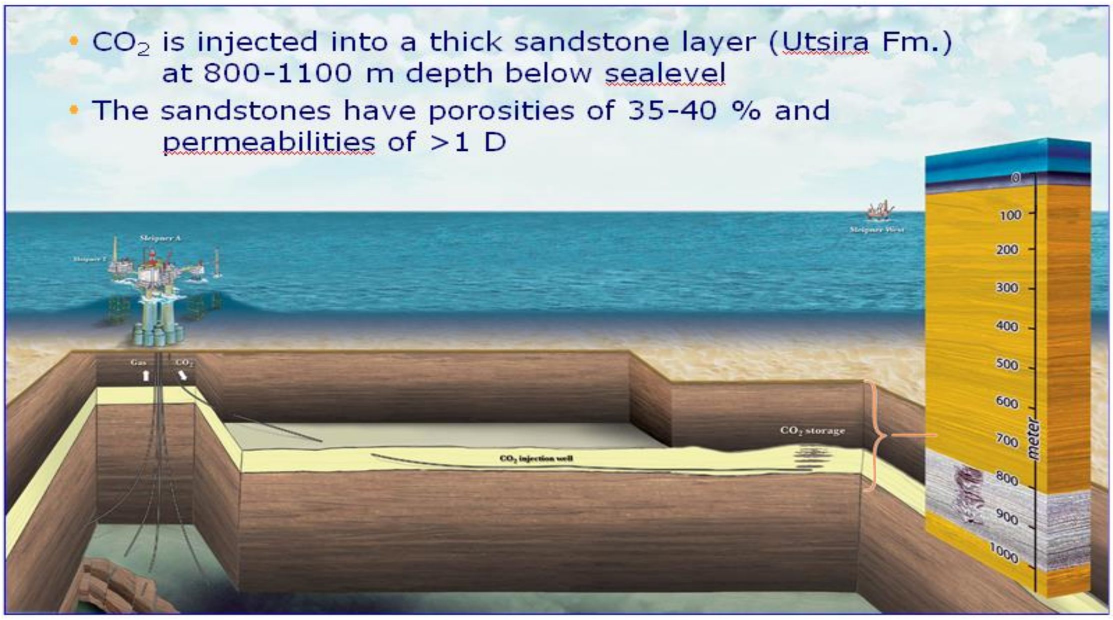


Figure 3.25: CO_2 capture from Sleipner Vest well stream and storage at Sleipner. Source: Equinor.

<u>Injection well</u>

In the Sleipner case it was very important to locate the injection well and the storage site such that the injected CO_2 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_2 leakage through production wells. The injection point is located 2.5 km east of the Sleipner A platform. Migration evaluations have been performed based on the Top Utsira map with the CO_2 expected to migrate vertically to the sealing shales and horizontally along the saddle point of the structure. This will take the CO_2 away from other wells drilled from the Sleipner platform.

The compressed CO_2 is transported by pipeline to the well head (injection well). The transport distance is 350 m, and the integrity of the pipeline is controlled by pressure monitoring.

<u>Monitoring</u>

The monitoring in the injection phase includes the following:

- Monitoring the presence, location and migration path of CO_2 in the in the reservoir using 4D seismic. The latest 4D seismic surveys were collected in 2016 and 2020.
- Monitoring of CO_2 pressure and temperature at the injection wellhead

- Monitoring of CO_2 volume flow
- Fall out test and stage rate tests

The CO_2 injection rate has been decreasing in recent years due to naturally falling gas production from the Sleipner fields. A brief summary of the results from the latest seismic survey, which was carried out in 2020, is given here.

There are no signs of leakage of CO_2 out of the storage formation. The elongated shape of the CO_2 plume confirms that no pressure build-up occurs in Utsira formation. In June 2020, the CO_2 plume was spread over an area of 5.2 km². Longest distance from the injection point was 3050 m, and the plume measured 5200 m from end to end. The distance from the CO_2 front to the nearest well (exploration well 15/9-13) was 305 m. The front of the plume has migrated westwards since 2010. This was expected, and the 2020 survey shows that a very small proportion of the CO_2 accumulation migrates this way.

CO_2 pressure and temperature at the wellhead of the CO_2 injector are continuously monitored. There is no downhole pressure gauge or temperature sensor installed. Historically, the injection pressure has been stable at around 65 bar. An alarm will be triggered at a wellhead pressure of 70 bar, and a shutdown function (trip) will be triggered at 75 bar.

CO_2 volume flow to injection is continuously monitored. The meter is located downstream the 4th-stage CO_2 compressor. A differential pressure-based flow meter is used to determine the volume of gas that is reinjected or vented to the atmosphere.

<u>Amounts of </u>CO_2

Table 3-42 gives the amount of CO_2 injected since the project started in 1996.

Table 3-42: CO_2 from the Sleipner field injected in the Utsira formation.

Year	CO_2 (ktonnes)
1996	70
1997	665
1998	842
1999	971
2000	933
2001	1 009

2002	955
2003	914
2004	750
2005	858
2006	820
2007	921
2008	814
2009	860
2010	743
2011	929
2012	842
2013	702
2014	658
2015	707
2016	632
2017	557
2018	509
2019	482
2020	506
2021	322
2022	115

Source: Equinor (Statoil) / the Norwegian Environment Agency

When the injection is stopped due to maintenance or any unplanned reasons, the captured CO_2 is vented to the atmosphere. The amount of CO_2 vented to the atmosphere is included in the greenhouse gas inventory reported under 1C1a. The emissions from venting are presented in Table 3-43.

Table 3-43: Emissions of CO_2 vented from the Sleipner Vest CO_2 –injection plant due to inaccessibility of the injection facility.

Year	CO_2 (ktonnes)
1996	81.0
1997	29.0
1998	4.2
1999	9.1
2000	8.3
2001	3.1
2002	87.6
2003	23.9
2004	21.4
2005	6.2
2006	2.5
2007	6.4
2008	13.6
2009	4.6
2010	0.9
2011	2.4
2012	5.9
2013	5.0
2014	5.4
2015	0.8
2016	4.6
2017	0.8
2018	1.6
2019	0.1
2020	1.2
2021	2.1
2022	0.3

Source: The Norwegian Environment Agency

By 31.12.2022, 19 million tonnes CO_2 have been injected and stored in the Utsira Formation and 0.33 million tonnes CO_2 have been vented.

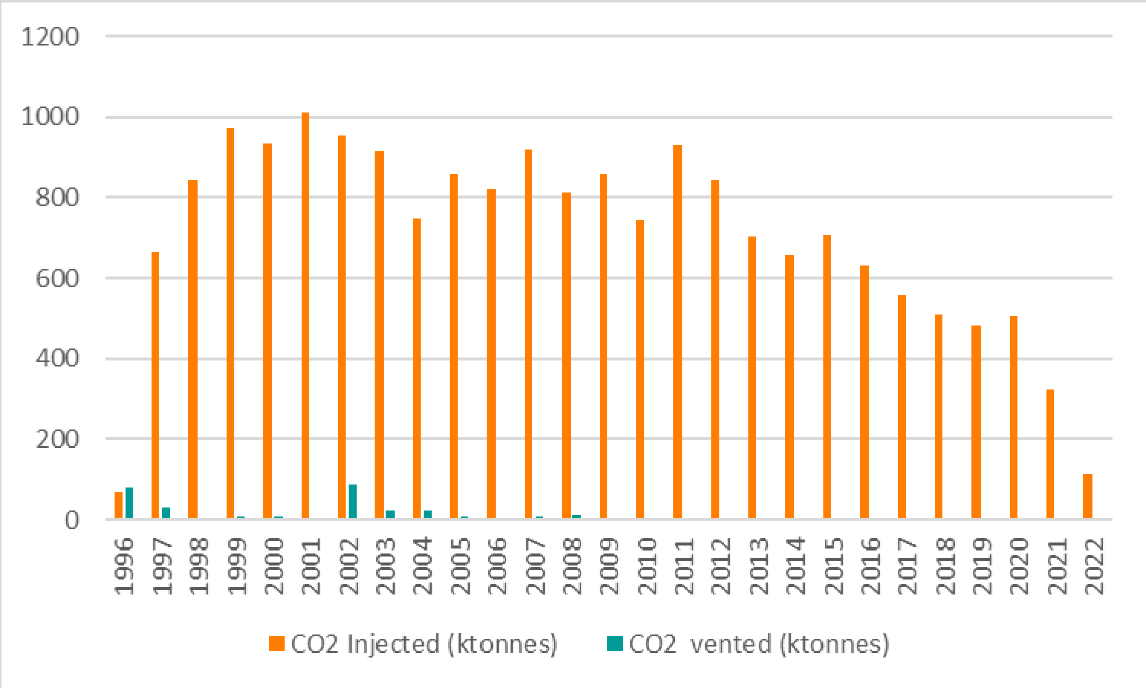


Figure 3.26 Injected and vented CO_2 at Sleipner Vest. Source: Norwegian Environment Agency.

Diffuse emissions from the CO_2 capture plant (amine absorber) and the CO_2 compressor are estimated to about 1,0 kt CO_2/year and these figures are included in CRF table 1.C.

3.4.2.2 Methodological issues

Equinor reports annually the amount of CO_2 injected and emitted to The Norwegian Environment Agency. The injected CO_2 is so far proven to be removed from the atmosphere and hence, it is not reported as emissions in the emission inventory.

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_2 injected in the Utsira formation are based on continuous metering of the gas stream by orifice meter. The composition of the CO_2 stream is stable, about 98% CO_2 and the remaining 2% mainly methane and heavier hydrocarbons.

The diffuse emissions are estimated based on equipment specific leakage factors. CO_2 detectors are monitoring almost all potential leakages sources (e.g., flanges).

3.4.2.3 Uncertainty assessment and time-series consistency

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_2 injected in the Utsira formation have $^{+}$/-3% accuracy. So far there has not been detected any leakage from the storage.

3.4.2.4 Category-specific QA/QC and verification

Storage of CO_2 is regulated by the Pollution Control Act and the specific regulations of geological storage of CO_2. Pursuant to the Pollution Control Act and the specific regulations, the operator shall hold a permit. When the injection of CO_2 is stopped for maintenance purposes, the operator pays a CO_2 tax for the emissions.

According to the permit conditions Equinor shall monitor the CO_2 storage.

From 2013 these emissions are included in the EU-ETS. In the national emissions inventory, the amount of CO_2 vented is reported under 1C2a - Injection.

The time-lapse seismic images clearly show the development of the CO_2 plume and have been used to calculate the amount of CO_2 in the reservoir. The volume calculated from the observed reflectivity and velocity pushdown is consistent with the injected volume.

3.4.2.5 Category-specific recalculations

There have been no recalculations performed for this source category this year.

3.4.2.6 Category-specific planned improvements

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

3.4.3 CO_2 capture and storage at Hammerfest LNG/Snøhvit

3.4.3.1 Description

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_2 per year into the geological formation, Tubåen. The LNG production and the CO_2 injection started in 2008. In 2018, the allowed amount was increased to 830 000 tonnes of CO_2 per year. The permit conditions were updated in 2017 in line with requirements in Directive 2009/31/EC of the European Parliament and of the Council on the geological storage of carbon dioxide the new Norwegian CO_2 storage regulations adopted in 2016.

The natural gas in the Snøhvit gas-condensate subsea field, including Albatross and Askeladd, in the Barents Sea contains about 5-7.5% CO_2. Prior to the LNG production the CO_2 must be removed to avoid it freezing out in the downstream liquefaction process and meet sales gas specifications.

The facilities for separation and injection of CO_2 are placed onshore at the Hammerfest LNG process plant onshore. An amine absorption unit performs the separation. The recovered CO_2 is condensed and recompressed before transported by a 152 km long subsea pipeline and re-injected into Stø formations. A schematic of the CO_2 re-injection system is shown in Figure 3.27.

About 0.8 Mtonnes CO_2 are removed from the feed gas every year at full production. During the expected lifetime of the field, about 23 million tonnes CO_2 from the feed gas will be removed and re-injected.

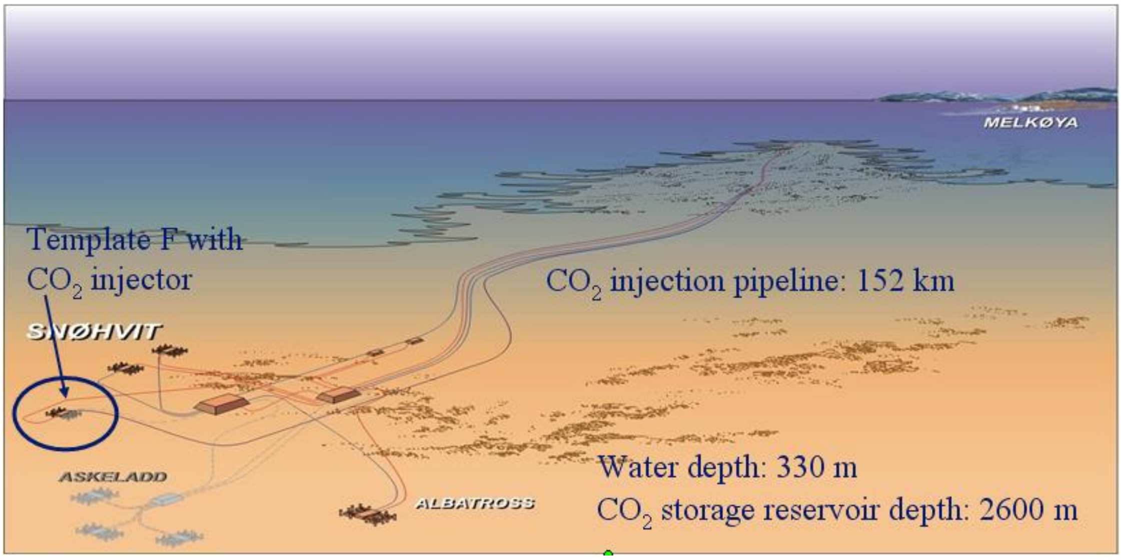


Figure 3.27: Snøhvit Field overview. Source: Equinor.

Reservoir

Several geological structures in the Snøhvit area were evaluated for disposal of CO_2. Among four structures identified as possible candidates for CO_2 storage the water bearing Tubåen Formation was chosen as the primary storage location.

In March 2011, the injection point was moved from Tubåen to the Stø reservoir, due to lower injectivity in Tubåen than expected.

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 mainly of sand. Formation depth is 2450 m below sea level.

CO_2 injection wells

The Snøhvit field has two CO_2 injection wells 7121/4-F-2 H (hereafter called F-2 H) and injection well 7121/4-G-4 H (hereafter called G-4 H), see figure 4.1. The injection well G-4 H is the primary injector, while F-2 H is the back up well in case G-4 H encounters challenges, and when the valves in G-4 H are tested.

CO_2 injected and vented

By 31.12.2022, 7 327 ktonnes have been injected into the Snøhvit field, and 521 ktonnes CO_2 have been vented (Table 3-44).

CO_2 venting occurs when the CO_2 reinjection system must shut down. The maximum vent rate is almost equal to the CO_2 removal flow rate. A separate vent stack for the CO_2 is provided at the plant.

Table 3-44: Injected and vented CO_2 Hammerfest LNG/Snøhvit field.

Year	CO_2 injected (ktonnes)	CO_2 vented (ktonnes)
2007	0	71
2008	197	94
2009	308	50
2010	460	93
2011	403	87
2012	490	55
2013	469	27
2014	587	37
2015	679	39
2016	750	4
2017	680	4
2018	758	11
2019	721	9
2020	422	1
2021	0	0
2022	402	11

Figure 3.27 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.

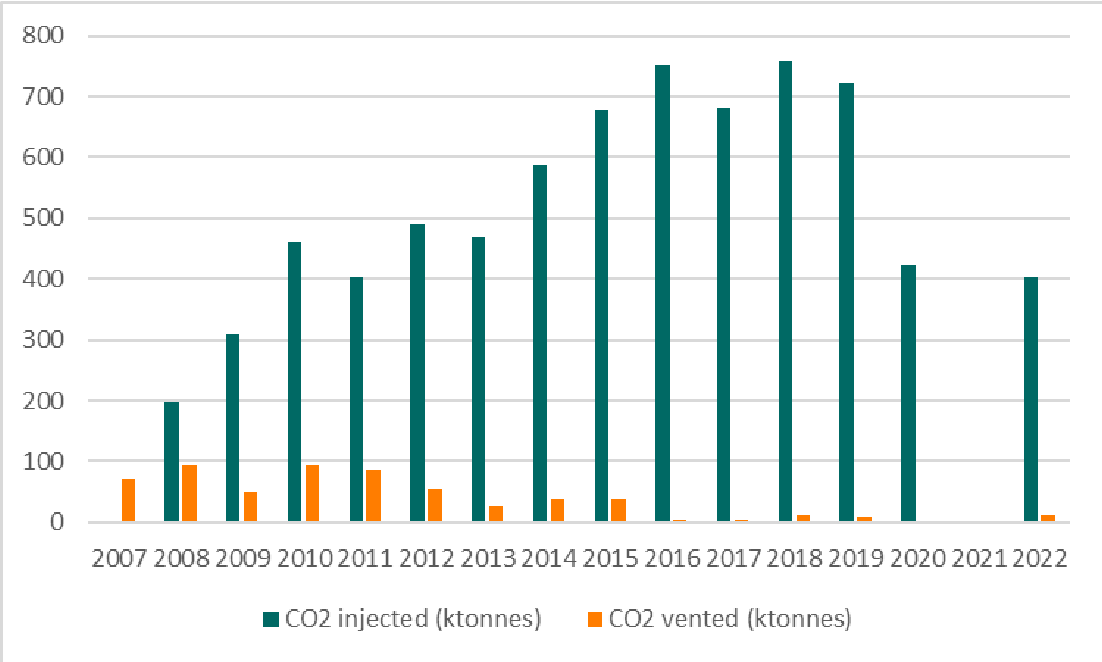


Figure 3.28: Injected and vented CO_2 at the Snøhvit field and Hammerfest LNG. Source: Equinor.

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_2 injection) was shut down for repair until May 2022. Thus, no CO_2 was injected in this period.

<u>Monitoring</u>

Hammerfest LNG uses a differential pressure-based flow meter to determine the amount of gas that remains reinjected (Tag 24-FE-1034, Orifice plate). The meter is located downstream of CO_2 recompression (E066-AB-24-PE-1004-001).

Pressure and temperature are monitored regularly as part of the daily operational monitoring of seabed installations. Pressure and temperature provide significant information about CO_2 migration in the reservoir. Fall-off tests are carried out regularly to check that no leaks have occurred in the pipeline system, and stage rate tests are used for monitoring CO_2 injectivity.

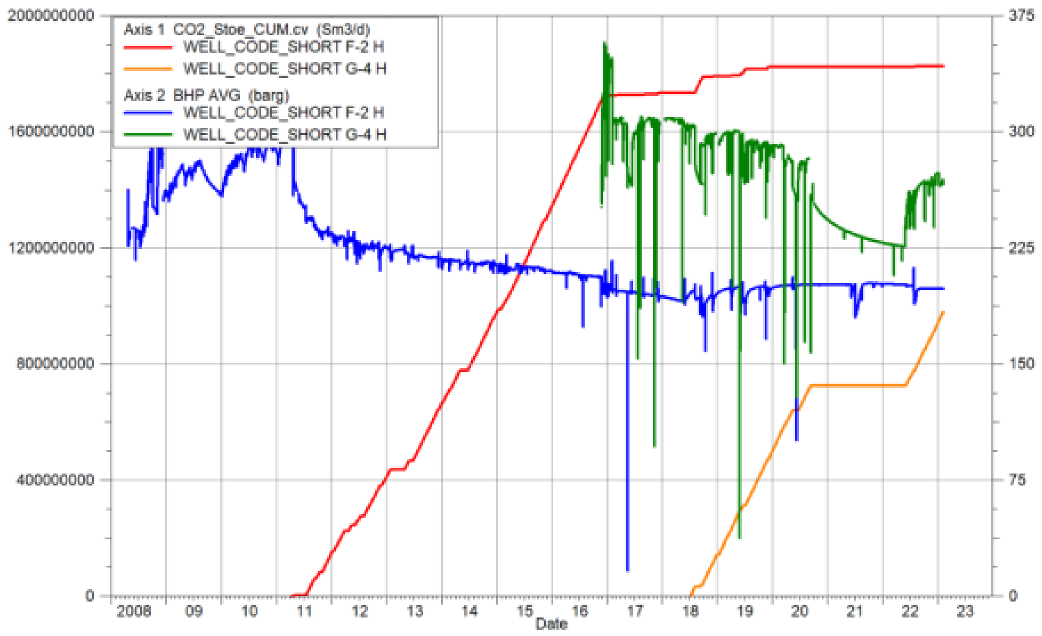


Figure 3.29: Bottom hole pressure and CO_2 volume injected into the Stø formation in F-2 H and in G-4 H.

Collection of 4D seismic data has been carried out in 2011, 2012, 2014 and 2019 and 2022. A base 4D survey was conducted in 2009. The next 4D seismic survey is planned to be carried out in 2025. So far, no irregularities in the CO_2 distribution and no CO_2 leakage out of the reservoir have been observed.

4D seismic has been used with good results to monitor the F-2 H and G-4 H CO_2 plume. *Figure 3.29* shows the development of the CO_2 plume in F-2 H from 2011 to 2019.

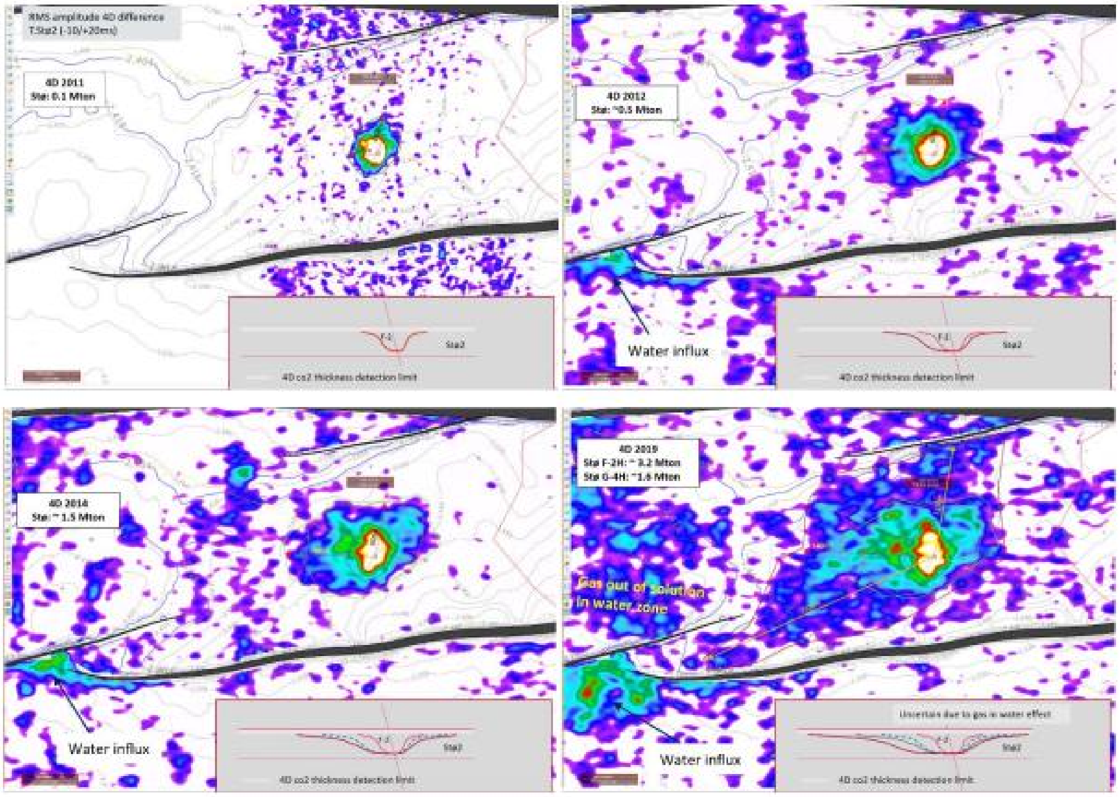


Figure 3.30: 4D RMS amplitude at Stø2 level. The approximate distribution of CO_2 is indicated in the figure. Sketch shows probable thicknesses of CO_2 in Stø 2, and that under approx. 7-9m thickness it is not possible to monitor the plume.

It is expected that when the CO_2 plume hits the oil and gas zone, the acoustic contrast between CO_2 and hydrocarbons become weaker, and one will most likely not be able to see the plume on 4D seismic. In 2019 and 2022, the 4D seismic shows no 4D effect when CO_2 most likely reaches the gas zone in the F segment.

Figure 3.31 and *Figure 3.32* shows 4D effects for 2019-2012 and 2022-2012 in the upper parts of Stø2 formation. In the G-4 H area, we still clearly see how CO_2 migrates westwards towards a shallower structure and lower pressure. Free gas in the water zone does not seem to be a problem here yet. Further west in the G-segment we see 4D softening effect which is most likely related to the occurrence of CO_2 in gaseous phase (gas out of solution) in the water zone. With more time for pressure drop, one can expect that this gas out of solution 4D effect also spreads towards G-4 H the area. This will make it more difficult to monitor CO_2 distribution in the future as we have seen in the F-2 H area.

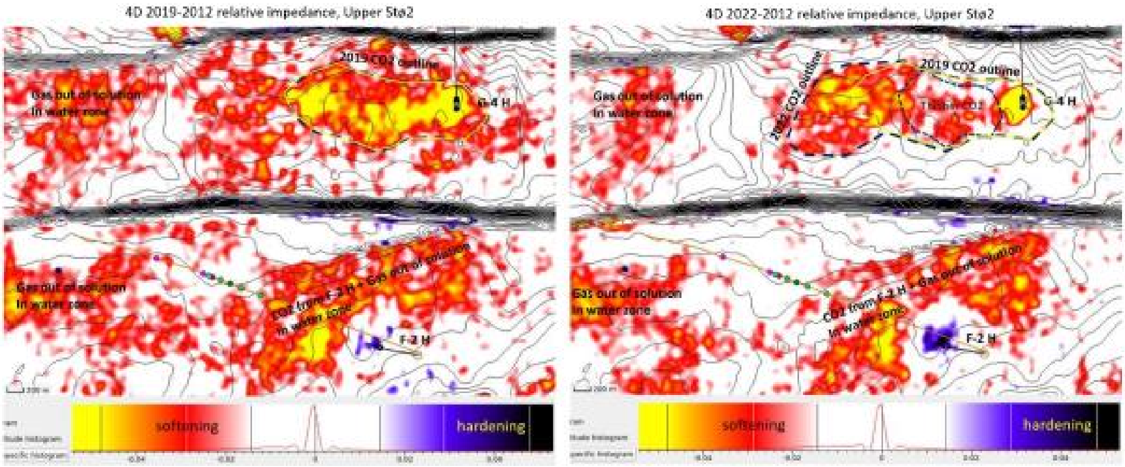


Figure 3.31: 4D relative acoustic impedance from 4D seismic inversion for 2019-2012 and 2022-2012 for upper parts of Stø2 Fm.

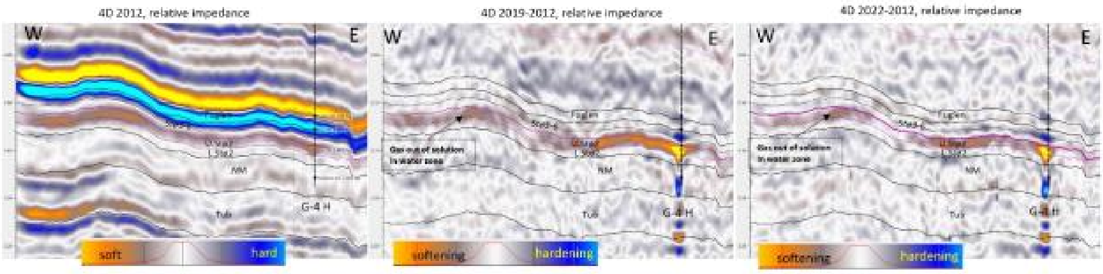


Figure 3.32: 4D relative impedance section from west to G-4 H in east for 2012, 4D difference 2019-2012 and 2022-2012. It is the upper parts of Stø2 Fm that take most of the injected CO_2 volumes in G-4 H.

Even if there are problems seeing the CO_2 spread in the reservoir due to gas out of solution, no CO_2 leakage out of the Stø Formation on the Snøhvit structure can be seen, which would most likely have been seen if that was the case.

An adapted reservoir simulation model is used to forecast pressure development and CO_2 migration. It focuses on both injectors and CO_2 migration area to the west. *Figure 3.33* shows how the injector G-4, and the backup injector F-2 are located in the reservoir, and how the model predicts that injected CO_2 will move in the reservoir towards shallower areas, and towards areas that have been pressure depleted due to natural gas production. This is compared with interpretations of the CO_2 plume from 4D seismic.

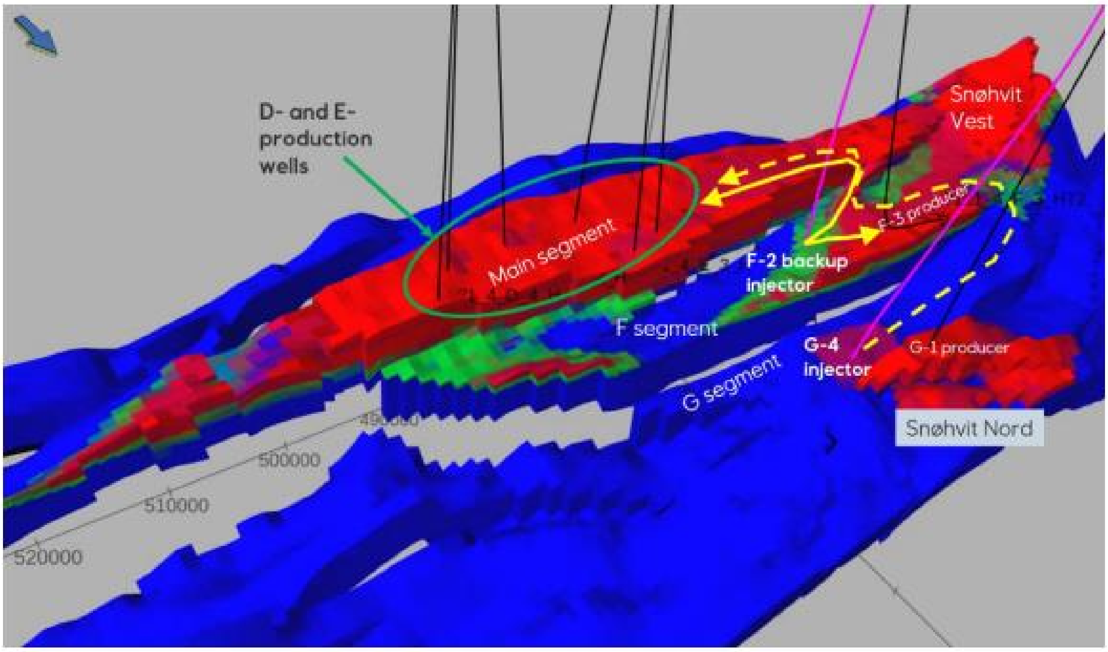


Figure 3.33: The reservoir simulation model shows how injected CO_2 is calculated to move in the reservoir (indicated by yellow arrows) towards shallower areas, and areas depleted due to production.

Equinor used a chemical gas tracer on the Snøhvit field in 2014 and 2018. The gas tracer with the trade name PMCP was injected into injection well G-4 H in 2018 and PMCH into F-2 H in 2014. The purpose of injection of tracer is to increase understanding of communication in the reservoir and obtain information on migration of stored CO_2.

An inspection was carried out in the pipeline in 2022 (Ref. Report from Deepocean EQ23605). By inspection of P142 CO_2 pipeline damage to the pipe has been observed and the pipe has been pulled out of position.

3.4.3.2 Methodological issues

CO_2 venting to atmosphere

The reported data covers CO_2 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_2 injector is measured by an orifice meter.
Gas composition of injected or vented gas from the CO_2 injector is controlled by analyses. This is primarily done as a quality assurance of the CO_2 removal system. Analyses have shown that the composition is 99.549% CO_2, 0.0066% H_2S, 0.331% CO_2 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_2.

Diffuse sources and pipeline transport

Diffuse emissions from the CO_2 capture plant are estimated to about 1,0 kt CO_2/year and these figures are included in CRF table 1.C.

For pipeline transport of CO_2, 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_2. 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.

3.4.3.3 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. A general assessment of time series consistency has not revealed any time series inconsistencies in the emission estimates for this category.

An uncertainty assessment of differential pressure-based flow meter measurements at Snøhvit has been performed, the resulting uncertainty is 5,89% (95% KI).

3.4.3.4 Category-specific QA/QC and verification

Operators for CO_2 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_2 storage. So far there is no sign of emissions to the water column or the atmosphere from the injected CO_2. Hence the CO_2 injected is not reported as emissions in the emission inventory. Statoil pays a CO_2 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_2 and the amounts of CO_2 injected are reported to the Norwegian Environment Authority. In the emissions inventory the of amount CO_2 vented at Hammerfest LNG (Snøhvit CO_2 storage project) – is reported under 1C2a - Injection 1B2c.

Equinor performs internal QA/QC for the ongoing CO_2 studies.

3.4.3.5 Category-specific recalculations

There have been no recalculations performed for this source category this year.

3.4.3.6 Category-specific planned improvements

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

4. Industrial processes and product use (CRF sector 2)

4.1 Overview of the sector

For most categories in the industrial processes and product use (IPPU) sector, 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.

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 4 and the specific QA/QC carried out for Industrial processes is described in Annex 5a.

Norway reports indirect emissions of CO_2 from oxidized CH_4 and NMVOC. The indirect CO_2 emissions from 2D3 (solvent use) and 2D3 (road paving with asphalt) are reported in the IPPU sector and indirect CO_2 emissions from some other source categories are reported in CTF tables 2, 6 and 10. Chapter 9 gives an overview of the source categories from which indirect CO_2 emissions are reported. The indirect emissions of CO_2 are calculated by Statistics Norway and are based on the emissions of CH_4 and NMVOC.

Table 4-1 gives an overview of the IPPU sector in Norway's GHG inventory. The GHG emissions from IPPU in 2022 were 9.3 million tonnes CO_2 equivalents and the emissions in 1990 were 14.8 million tonnes CO_2 equivalents. The emissions from this source category have decreased by 37.1% from 1990 to 2022 and increased by 0.5% from 2021 to 2022. The decrease from 1990 to 2022 is mainly due to reduced PFC emissions from production of aluminium and SF_6 from production of magnesium. The reduction in the SF_6 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_6 as tracer gas. In June 2006, the magnesium recycling foundry also closed. In addition, N_2O emissions from nitric acid production have decreased substantially since 1990.

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 according to the key category analysis.

Table 4-1: Emission trends for IPPU categories (ktonnes CO_2 equivalents).

Category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2A	730.8	4.9%	939.1	992.1	10.6%	35.8%	5.7%
2B	3 899.1	26.3%	1 835.2	1 887.1	20.2%	-51.6%	2.8%
2C	9 780.6	66.0%	5 317.9	5 274.8	56.6%	-46.1%	-0.8%
2D	287.5	1.9%	245.7	231.2	2.5%	-19.6%	-5.9%
2E	NO	NA	IE	IE	NA	NA	NA
2F	0.0	0.0%	743.2	746.8	8.0%	1503091.8%	0.5%
2G	85.4	0.6%	85.6	85.4	0.9%	0.0%	-0.2%
2H	31.3	0.2%	112.7	106.1	1.1%	239.3%	-5.8%
Total	14 814.7	100.0%	9 279.2	9 323.5	100.0%	-37.1%	0.5%

Source: Statistics Norway and the Norwegian Environment Agency

Table 4-2: Key categories in the sector Industrial processes and product use.

CRF code	Source category	Gas	Identification criteria [1]	Method
2A1	Cement production	CO_2	L1	Tier 3
2A2	Lime production	CO_2	T1	Tier 3
2B1	Ammonia production	CO_2	L1, L2	Tier 2
2B2	Nitric Acid Production	N_2O	L1, T1, L2, T2	Tier 3
2B5*	Carbide production	CO_2	T1, T2	Tier 2
2B8**	Petrochemical and carbon black production	CO_2	L1, L2	Tier 2
2C2	Ferroalloys production	CO_2	L1, T1, L2	Tier 2/ 3
2C3	Aluminium production	CO_2	L1, T1, L2, T2	Tier 2/ 3
2C3	Aluminium production	PFCs	L1, T1, L2, T2	Tier 2
2C4	Magnesium production	SF_6	L1	Tier 2
2F	Product uses as substitutes for ODS	HFCs	L1, T1, L2, T2	Tier 2

Source: Statistics Norway and the Norwegian Environment Agency
[1] "L" refers to level and "T" to trend analyses. Numbers refer to approaches.
** 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.*

4.2 Mineral industry – 2A

The sector category Mineral industry includes CO_2 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 (see Table 4-3).

Table 4-3: Mineral industry. Component included in the inventory, tier of method and key category.

Source category	CO_2	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: Emission trends for 2A Mineral industry (ktonnes CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2A1. Cement production	634.3	4.3%	698.6	710.3	7.6%	12.0%	1.7%
2A2. Lime production	49.8	0.3%	206.0	251.7	2.7%	404.9%	22.2%
2A3. Glass production	5.6	0.0%	8.0	7.7	0.1%	38.6%	-3.3%
2A4a. Ceramics	3.7	0.0%	0.0	0.0	NA	-100.0%	NA
2A4b. Other uses of soda ash	9.0	0.1%	4.4	4.2	0.0%	-53.0%	-4.3%
2A4c. Non metallurgical magnesium production	0.0	0.0%	2.7	0.0	0.0%	NA	-100.0%
2A4d. Other process use of carbonates	28.4	0.2%	19.3	18.2	0.2%	-35.9%	-5.7%
Total 2A.	730.8	4.9%	939.1	992.1	10.6%	35.8%	5.7%

Source: Statistics Norway and the Norwegian Environment Agency

Table 4-4 shows that the CO_2 emissions from this sector category were about 1.0 million tonnes in 2022, this accounts for 10.6% of the total emission from the IPPU sector. The emissions from this sector have increased with 35.8% from 1990 to 2022, mainly due to increased production of clinker and lime in more recent years. The emissions from this sector category increased by 5.7% from 2021 to 2022. 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.

Table 4-5: Balance in ktonnes in recent years for the use of limestone in IPPU.

Limestone use	2018	2019	2020	2021	2022
2A1 - Cement production	1 659	1 640	1 647	1 588	1 614
2A2 - Lime production	457	416	436	478	562
2A3 – Glass production	0	0	0	0	0
2A4a – Ceramics	NA	NA	NA	NA	NA
2A4c – Non-metallurgical magnesium production	0	0	0	0	NA
2A4d – Other process uses of carbonates	0	0	0	0	0.2
2C2 - Production of ferroalloys	34	35	38	30	32
2H1 – Pulp and paper	19	19	20	21	20
Total limestone	2 169	2 111	2 141	2 116	2 228

Table 4-6: Balance in ktonnes in recent years for the use of dolomite in IPPU.

Dolomite use	2018	2019	2020	2021	2022
2A2 - Lime production	30	55	16	10	32
2A4c – Non-metallurgical magnesium production	67	109	50	7	NA
2A4d – Other process uses of carbonates	17	10	13	18	16
2A3 - Glass production	12	13	12	14	13
2C2 - Production of ferroalloys	17	9	2	4	8
Total dolomite	143	197	93	53	69

There is no information that indicates that there are other emissive uses of limestone and dolomite that are not reported. 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.

4.2.1 Cement Production, 2A1 (Key category for CO_2)

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 ($CaCO_3$). The resulting calcium oxide is heated to form clinker and then crushed to form cement. CO_2 from cement production is defined as a key category.

4.2.1.2 Methodological issues

The emissions of CO_2 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(I).A-Hs1 and Table 4-7 shows the clinker production for some selected years in the time series.

Table 4-7: Norwegian clinker production (ktonnes).

Year	Total production
1990	1 244.1
1995	1 682.9
2000	1 649.6
2005	1 454.3
2010	1 433.8
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
2022	1 390.7

Source: Statistics Norway and the Norwegian Environment Agency

4.2.1.4 Emission factors

CO_2

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_2 per tonne clinker for one plant (Tokheim 2006) and 0.541 tonne CO_2 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_2/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 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5A. 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_2 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_2)

4.2.2.1 Category description

Three plants that produce lime in Norway reported CO_2 emissions from processes to the Norwegian Environment Agency and all three plants are covered by the EU ETS. The large increase in CO_2 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_2 from lime production is defined as a key category.

4.2.2.2 Methodological issues

All three plants calculate the emissions of CO_2 based on the input of limestone and dolomite and plant specific emission factors for CO_2 from limestone and dolomite respectively. The emissions are reported to the Norwegian Environment Agency in accordance with the reporting requirements of the EU ETS[19] 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
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
2020	453.4	251.7
2021	488.8	272.5

[19] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012R0601-20190101&from=EN

2022	595.8	332.3

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_2 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 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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.

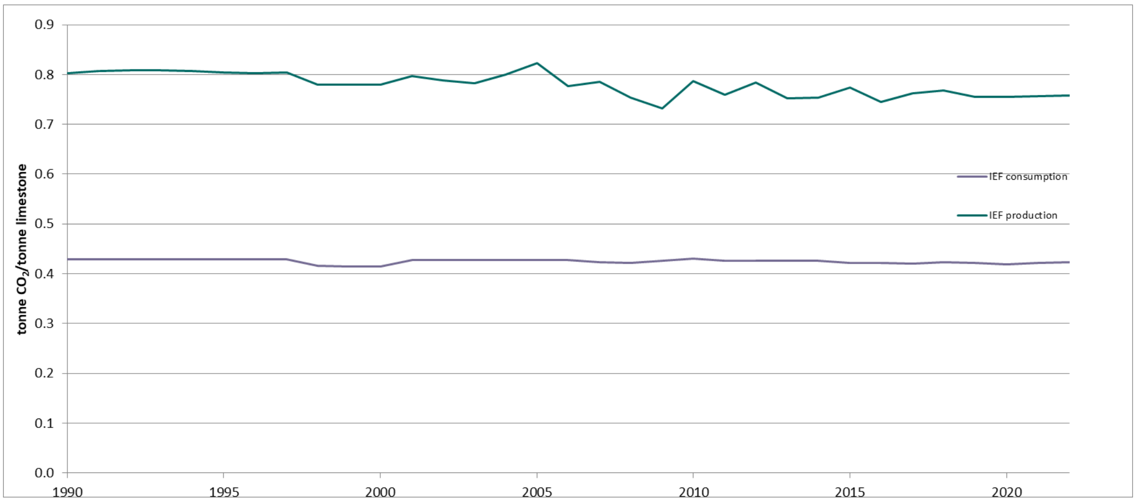


Figure 4-1: IEF (tonne CO_2 per tonne limestone) with consumption or production as AD. Source: Norwegian Environment Agency.

4.2.2.6 Category-specific QA/QC and verification

The specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2 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_2/tonne soda ash (IPCC 2006), 0.477 tonnes CO_2/tonne dolomite (EU ETS) and 0.44 tonnes CO_2/tonne limestone (EU ETS).

4.2.3.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2 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_2 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_2 per tonne clay used.

4.2.4.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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_2 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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 2C7aii (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_2 emissions are estimated and reported here under 2A4b.

4.2.5.2 Methodological issues

The emission figures for CO_2 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 (Other uses of soda ash)	2A3 (Glassworks)	2C3 (Aluminium production)	2C7ii (Nickel 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	38.1	NO	3.5	0.9	33.6
2013	51.7	11.1	4.0	0.9	35.8
2014	47.4	5.1	3.4	1.1	37.8
2015	44.0	2.6	4.0	1.2	36.2
2016	47.7	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	10.7	3.2	1.1	37.6
2022	45.8	10.2	3.4	0.9	31.3

4.2.5.4 Emission factors

The emission factor for soda ash use is 0.41492 tonnes CO_2/tonne soda ash from the IPCC 2006 Guidelines (IPCC 2006).

4.2.5.5 Uncertainty assessment 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_2 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_2 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(I).A-Hs1 and Table 4-10 shows the usage for some selected years in the time series.

Table 4-10: Usage (kt) of limestone and dolomite in the non-metallurgical magnesium production.

Year	Limestone use	Dolomite use
2005	0.0	1.4
2010	1.4	0.0
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	0.00	6.6
2022	0	0

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 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2 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 now uses only fly ash. The use of fly ash reduces the CO_2 emissions compared with when limestone is used. Finally, the category includes CO_2 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_2 emissions to the Norwegian Environment Agency. The leca producer that still is in operation also reports. some process emissions that are not from the use of dolomite. This includes the use of clay, waste oil mixed into the clay as an additive and scraps of glass wool. 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_2 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_2 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, waste oil, scraps of glass wool 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 some of the activity data for some selected years in the time series.

Table 4-11: Use of limestone, dolomite, clay and fly ash in 2A4d (other process use of carbonates), all in kt.

Year	Limestone	Dolomite	Clay	Fly ash	Scraps of glass wool
2010	0.0	8.7	174.0	118.3	0.0
2013	33.9	17.7	155.5	128.5	0.0
2014	0.0	16.3	135.0	129.9	0.0
2015	0.0	15.3	99.5	132.6	0.0
2016	0.0	11.5	133.2	145.2	0.0
2017	0.0	15.6	147.9	152.5	0.0
2018	0.0	17.4	154.2	127.6	0.0
2019	0.0	10.1	154.7	98.3	0.0
2020	0.0	12.6	112.0	112.9	0.4
2021	0.0	18.3	145.3	51.3	14.2
2022	0.2	16.4	140.0	48.4	21.3

Source: Norwegian Environment Agency

4.2.7.4 Emission factors

An emission factor (EF) of 0.48 t CO_2/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 $CaCO_3$ and $MgCO_3$ 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 EF for the waste oil mixed into clay is 3.2 t CO_2/t waste oil and the EF for scraps of glass wool is in the range of 0.318 to 0.338 t CO_2/t scrap of glass wool. The plant that neutralizes sulphuric acid waste uses an emission factor of 0.44 t CO_2/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_2/t fly ash and with an average of 72.7 based on activity data and emissions. The IEF of 68.5 kg CO_2/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_2/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_2/t limestone and 0.481 t CO_2/t dolomite.

4.2.7.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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 are recalculations performed for this source category this year, see chapter 10 for details.

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_2	CH_4	N_2O	NMVOC	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	No
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***
2B10. Other	NA	NA	R	NA	Tier 3	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.
** In the key category analysis, 2B5a and 2B5b have been aggregated to 2B5.*
***Minor N_2O emissions from 2B8a and 2B8b are reported under 2B10 Petrochemical N_2O 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 1.9 million tonnes in 2022, this is 20.2% of the total emission from the IPPU sector. The emissions from this sector decreased by 51.6% from 1990, mainly due to lower emissions from the production of nitric acid, ammonia and carbide. The emissions increased by 2.8% from 2021 to 2022.

Table 4-13: Emission trends for 2B Chemical industry (kt CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2B1. Ammonia production	795.2	5.4 %	543.6	700.3	7.5 %	-11.9 %	28.8 %
2B2. Nitric acid production	1 772.6	12.0 %	48.9	51.9	0.6 %	-97.1 %	6.2 %
2B5a. Silicon carbide production	245.6	1.7 %	48.3	41.0	0.4 %	-83.3 %	-15.0 %
2B5b. Calcium carbide production	178.1	1.2 %	0.0	0.0	0.0 %	-100.0 %	NA
2B6. Titanium dioxide production	201.1	1.4 %	275.6	247.9	2.7 %	23.3 %	-10.1 %

2B8a. Methanol production	0.0	0.0 %	226.9	230.3	2.5 %	NA	1.5 %
2B8b. Ethylene production	606.9	4.1 %	547.4	418.2	4.5 %	-31.1 %	-23.6 %
2B8g. Other	47.8	0.3 %	19.6	22.3	0.2 %	-53.4 %	13.6 %
2B10. Petrochemical N_2O	0.2	0.0 %	0.4	0.4	0.0 %	147.0 %	4.6 %
2B10. Other (production of fertilizers)	51.5	0.3 %	124.6	174.9	1.9 %	239.4 %	40.4 %
2B. Total	3 899.1	26.3 %	1 835.2	1 887.1	20.2 %	-51.6 %	2.8 %

Source: Statistics Norway and the Norwegian Environment Agency

4.3.1 Ammonia Production, 2B1 (Key category for CO_2)

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_2 is recovered from the production process. CO_2 from ammonia production is defined as a key category.

Figure 4-2 shows the time series for the gross CO_2 emissions, amount of recovered CO_2 and the net CO_2 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.

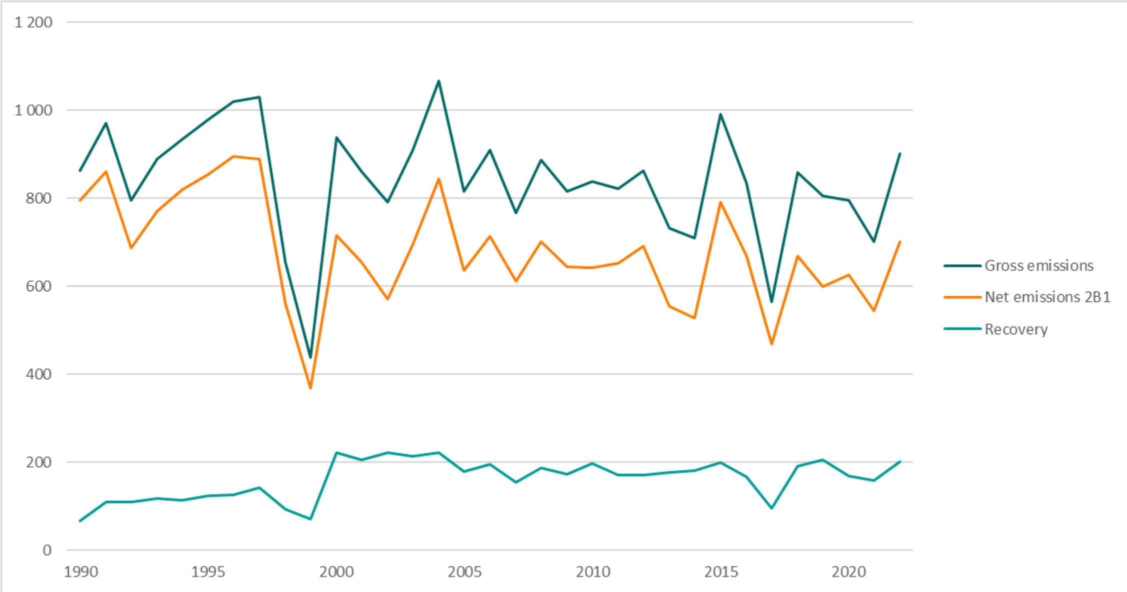


Figure 4-2: CO_2 emissions from production of ammonia. Source: Norwegian Environment Agency.

4.3.1.2 Methodological issues

The CO_2 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_2. A part of the $CO_{2,}$ 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_2 recovered by the plant is determined by using the amount of CO_2 from the compressor unit minus the amount of CO_2 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_2 reported as recovered that is not exported is included in 2H2 Food and Drink.

Subtracting the captured CO_2 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_2 and reported emissions in 2B1.

Table 4-14: Activity data, emission factors and balance for 2B1 in 2022.

	ktonnes	Emission factor (tonne CO_2/tonne)	ktonnes CO_2
Heating oil	0.5	3.17	1.4
Liquefied petroleum gas	79.6	3.000291631	239
CO-rich gas	27.0008	1.272517855	34.4
Ethane	214.1	2.927095792	626.8
Gross emissions			901.2
Captured CO_2			200.9
Net emissions in 2B1			700.3

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 Uncertainty assessment 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 ± 0.2 and ethane ± 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.

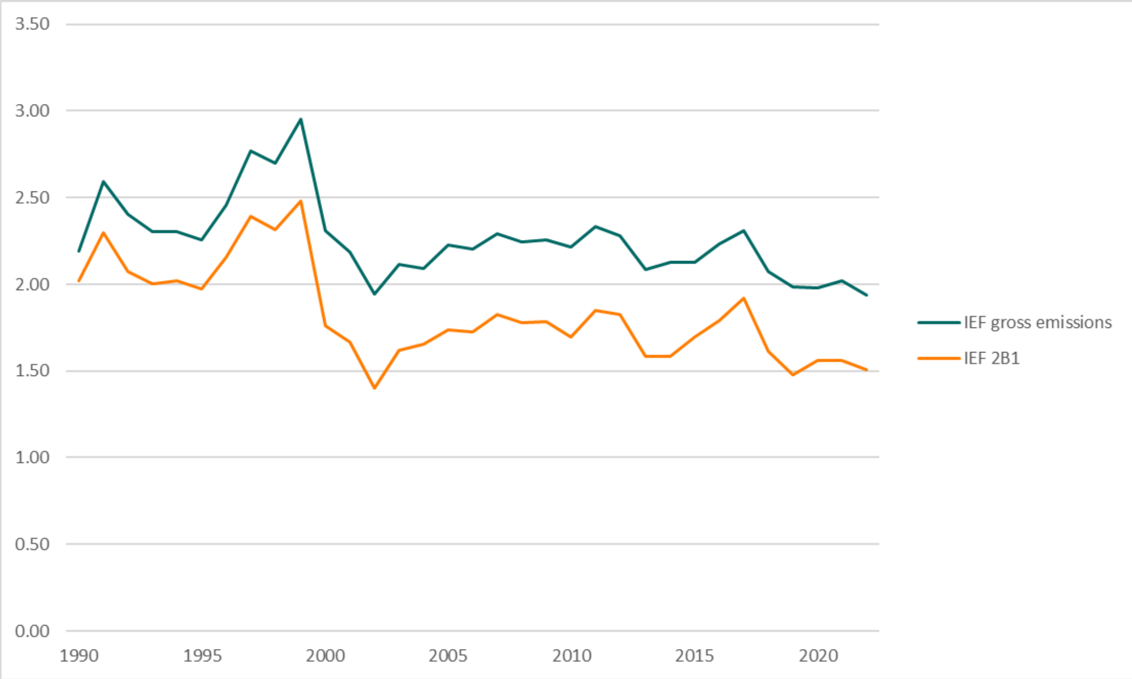


Figure 4-3: IEF for process emissions of CO_2 from ammonia production (tonne CO_2/tonne ammonia). Source: Norwegian Environment Agency.

4.3.1.6 Category-specific QA/QC and verification

The specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2/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_2O)

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_3) generates nitrous oxide (N_2O) and NO_x as by-products of high temperature catalytic oxidation of ammonia (NH_3). N_2O from nitric acid production is defined as a key category.

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_2O 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_2O 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% from 2009 to 2010 that came after a decrease in production of about 26% 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_2O

The two plants report the emissions of N_2O to the agency. The N_2O 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.[20]

4.3.2.3 Activity data

The plants report the amounts of N_2O in the gas, based on continuous measurements. The plants also report the production of HNO_3 to the agency. The production and emission levels are shown for some years in

[20] 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 continous measurements under the EU ETS.

Table 4-15.

Table 4-15: Production (ktonnes HNO_3) and N_2O emissions (ktonnes).

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
2022	2 028.8	0.196

Source: Statistics Norway and Norwegian Environment Agency

4.3.2.4 Emission factors

Not relevant.

4.3.2.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. The uncertainty in the measurements was in 2000 estimated by the plant to ±7%. However, in the 2006 report to the Norwegian Environment Agency one plant reports that the uncertainty in measurement of N_2O is calculated to ±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.

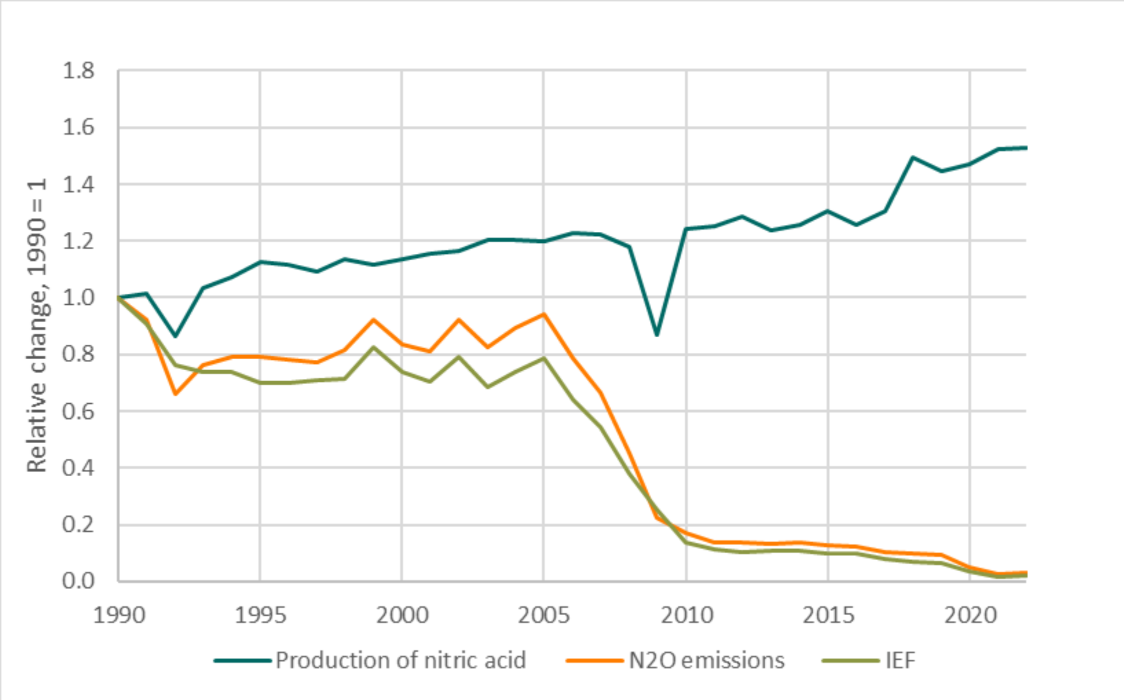


Figure 4-4: Relative change in total emissions, total production and IEF for nitric acid production. 1990=1. Source: Norwegian Environment Agency.

4.3.2.6 Category-specific QA/QC and verification

The specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2)

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_2) with petrol coke as a reducing agent. In the production of silicon carbide, CO_2 and CO is released as a by-product from the reaction between quartz and carbon. Methane (CH_4) 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_2 from carbide production is defined as a key category.

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_2

Emission figures are reported annually by the three plants to the agency.
CO_2 from process is calculated based on activity data and emission factors. The three production sites have used amount of produced crude silicon carbide as activity data in the calculation of CO_2 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_4

The emission of CH_4 from production of silicon carbide is calculated based on activity data and emission factors. 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_2 are reported in CRF table 6 and are calculated by Statistics Norway based on the emission of CH_4 and NMVOC.

4.3.3.3 Activity data

The activity data used by the plants for the calculation of *CO_2*, *CH_4* 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
2013	16.9
2014	17.9
2015	17.6
2016	18.7
2017	21.2
2018	21.7
2019	18.5
2020	16.5
2021	16.4
2022	14.2

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_2/tonne crude silicon carbides, see

Table 4-18. 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 in 2022 is therefore slightly lower than 2.62. All plants use the default emission factor of 11.6 kg CH_4 /tonnes crude SiC from the IPCC 2006, see Table 4-17.

Table 4-17: Emission factor for CO_2 and CH_4 used for silicon carbide production.

Component	Emission factor	Source
CO_2	2.62 tonnes CO_2/tonnes crude SiC	IPCC 2006
CH_4	11.6 kg CH_4 /tonnes crude SiC	IPCC 2006

For NMVOC, an emission factor of 10.8 t NMVOC/kt Sic is used for the whole time series. This is based on measurements by the plants.

4.3.3.5 Uncertainty assessment and time-series consistency

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 ± 3%. The uncertainty in the emission factors for CO_2 and CH_4 are $\pm$10%. This is the default value in the IPCC 2006 Guidelines. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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

There have been no recalculations performed for this source category this year.

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_2 in 1990. The production of calcium carbide generates CO_2 emissions when limestone is heated and when petrol coke is used as a reducing agent.

4.3.4.2 Methodological issues

The CO_2 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_2 has been estimated to be 1.69 tonne/tonne CaC_2 by SINTEF (1998b). An additional 0.02 t CO_2 /t CaC_2 from fuel is reported in the Energy chapter.

4.3.4.5 Uncertainty assessment and time-series consistency

For uncertainty, see description for 2B5a. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a.

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

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_2 are emitted during the production process.

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_2 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.

Table 4-18: Carbon inputs (ktonnes) for titanium dioxide production in 2022.

Activity data	Amount (ktonnes)
Coal	72.9
Iron	76.9
Antracites	5.1
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.

Table 4-19: Emission factors for some of the carbon inputs in 2022.

Activity data	EF (tonne CO_2/tonne)
Coal	2.51272
Iron	0.15129
Antracites	3.06085
Electrode mass (tonne dry weight)	3.49024

Source: Norwegian Environment Agency

4.3.5.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_4, N_2O 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_2 emissions from other energy combustion (diesel and propane) are included under 1.A.2.C. Indirect emissions of CO_2 are reported in CRF table 6 and are calculated by Statistics Norway based on the emission of CH_4 and NMVOC, see chapter 9 for details about EFs. Minor N_2O emissions are reported under 2B10 Petrochemical N_2O in the CRF.

4.3.6.2 Methodological issues

The plant reports emission figures of CO_2, CH_4, N_2O and NMVOC to the Norwegian Environment Agency. The reported CO_2 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.

Most of the CH_4 emissions reported by the plant are from a washing tower. The CH_4 emissions from this source were first estimated by the plant for the year 2022 and were estimated based on measurements of the composition of gases and the number of operating hours in a monthly basis. The emissions from this source for the years 1997-2021 were estimated by the plant by using the IEF for 2022 (t CH_4 emissions per tonne methanol produced) multiplied by the annual methanol production.

The plant reports diffuse CH_4 and NMVOC emissions based on the use of infrared cameras twice during a year to estimate an emission factor per operating hour. The emissions reported by the plant for 2021 and 2022 have been used by the Norwegian Environment Agency to calculate an average IEF for 2021 and 2022 (t CH_4 and NMVOC emissions per tonne methanol produced) and this is multiplied with the annual methanol production to estimate emissions for the years 1997-2020. Similarly, the CH_4 and NMVOC emissions from flaring and combustion are from 2021 as reported by the plant. For the years prior to 2021, the Norwegian Environment Agency have calculated an average IEF for 2021 and 2022 and multiplied this with the annual methanol production.

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 2022 was about 581 ktonnes and the time series for the production is reported in CRF table2(I).A-Hs1.

Table 4-20: Sum of fuels (kt) used in methanol production.

2017	2018	2019	2020	2021	2022
138	125	126	122	101	100

Source: Norwegian Environment Agency

The activity data used to calculate the indirect CO_2 emissions are the diffuse emissions of CH_4 and NMVOC.

4.3.6.4 Emission factors

CO_2

The plant reports its emission factors to the Norwegian Environment Agency. The EF for natural gas is stable at around 2.70 tonnes CO_2 per tonne natural gas. The EF for the flaring gas varies. The EF for syngas is at around 1.2-1.3 tonnes CO_2 per tonne syngas and the EF for LOFS is around 0.3 tonne CO_2 per tonne LOFS.

4.3.6.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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

There are recalculations performed for this source category this year, see chapter 10 for details.

4.3.6.8 Category-specific planned improvements

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

4.3.7 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_2 emissions from the production of ethylene, but there are also CO_2 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 that are reported under 1A2C. Emissions of CH_4 and NMVOC emissions from leakages in the process are also included. Indirect emissions of CO_2 from CH_4 and NMVOC are reported in CRF table 6. Minor N_2O emissions are reported under 2B10 Petrochemical N_2O in the CRF. Further emissions of N_2O from combustion are reported in 1A2c.

4.3.7.2 Methodological issues

CO_2, CH_4 and NMVOC

The plants report emission figures of CO_2, CH_4, N_2O 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_2 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_4 and NMVOC emissions are based on measurements and are reported to the Norwegian Environment Agency.

Indirect emissions of CO_2 calculated by Statistics Norway are based on the emission of CH_4 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 2022 were about 422 ktonnes and 344 ktonnes respectively.

Table 4-21: Sum of fuels (kt) used in 2B8b.

2017	2018	2019	2020	2021	2022
560	569	529	570	573	419

Source: Norwegian Environment Agency

The CH_4 and NMVOC emissions are reported annually to the Norwegian Environment Agency. The activity data used to calculate the indirect CO_2 emissions are the diffuse emissions of CH_4 and NMVOC.

4.3.7.4 Emission factors

CO_2

The plants report the emission factors used as part of their reporting under the EU ETS.

CH_4

For the plant producing vinyl chloride, the reported diffuse emissions of CH_4 are based on a measurement derived emission factor of 5 kg CH_4 per operating hour. See chapter 9 for details concerning the EFs used for indirect CO_2 emissions from CH_4 and NMVOC.

4.3.7.5 Uncertainty assessment and time-series consistency

Uncertainty estimates are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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

There have been no recalculations performed for this source category this year.

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_2, CH_4 and NMVOC

The plant producing polyethylene reports emission figures of CO_2, CH_4 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_4 and NMVOC emissions reported are based on measurements. Indirect emissions of CO_2 calculated by Statistics Norway are based on the emissions of CH_4 and NMVOC.

The plant that produces formalin and binders reports CO_2 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_2 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.

2016	2017	2018	2019	2020	2021	2022
5	4	5	5	5	7	7

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 2022 was about 94 ktonnes and the production of formalin (100%) in 2022 was about 34 ktonnes.

4.3.8.4 Emission factors

CO_2

The plants report the emission factors used as part of their reporting under the EU ETS.

4.3.8.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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

There have been no recalculations performed for this source category this year.

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.

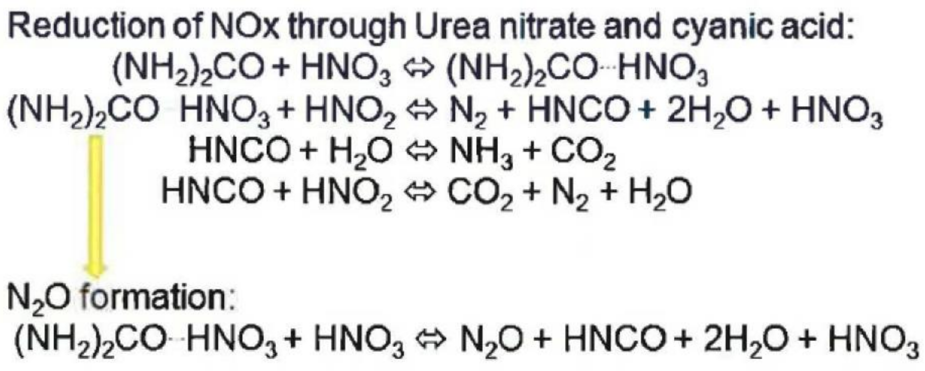
4.3.9 Other, production of fertilizers, 2B10

4.3.9.1 Category description

A plant producing fertilizers has since 2011 reported N_2O emissions from its production to the agency. Urea nitrate is added to the process to reduce the formation of NO_x emissions and this process forms N_2O emissions.

4.3.9.2 Methodological issues

According to the plant, the formation of NO_x is reduced through the use of urea nitrate and cyanic acid. The process forms N_2O, see formulas below.



The emissions of N_2O are based on measurements of gas volumes and samples are taken for analysis by gas chromatograph. The plant has reported N_2O 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_2O 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 Uncertainty assessment 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 2.

4.3.9.6 Category-specific QA/QC and verification

The specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2	CH_4	PFCs	SF_6	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_2O emissions from 2C2 are reported under 2C7 Ferroalloys N_2O 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 2022, this is 56.4% of the total emission from the IPPU-sector. The largest contributors to the GHG emissions from Metal industry in 2022 are Ferroalloy production and Aluminium production. The emissions from Metal Production have decreased by 46.2% from 1990. The reduction since 1990 is due to decreased PFC and SF_6 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 decreased by 0.8% from 2021 to 2022. 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.

Table 4-24: Emission trends for 2C Metal industry (kt CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2C1a. Iron and steel production	12.4	0.1 %	32.6	34.4	0.4 %	178.6 %	5.6 %
2C2. Ferroalloys production	2 555.0	17.2 %	2 786.9	2 819.9	30.2 %	10.4 %	1.2 %
2C3. Aluminium production	4 918.8	33.2 %	2 390.3	2 317.6	24.9 %	-52.9 %	-3.0 %
2C4. Magnesium production	2 235.6	15.1 %	NO	NO	NA	-100.0 %	NA

2C6. Zink production	3.0	0.0 %	4.9	4.2	0.0 %	42.7 %	-13.7 %
2C7 Ferroalloys N_2O	4.5	0.0 %	3.7	4.1	0.0 %	-8.1 %	10.6 %
2C7 Anode production	43.8	0.3 %	83.9	81.5	0.9 %	86.0 %	-2.9 %
2C7 Nickel production	7.6	0.1 %	15.6	13.0	0.1 %	71.1 %	-16.7 %
2C. Total	9 780.6	66.0 %	5 317.9	5 274.8	56.6 %	-46.1 %	-0.8 %

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_2 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_2 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 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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_2 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2)

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 quarts (SiO_2). 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 CO_2 and 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 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 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 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 CH_4 emissions originates from the use of coal and coke in the production processes. From the production of ferro manganes (FeMn), silicon manganes (SiMn) and ferrochromium (FeCr) there is only CO_2 emissions. Measurements performed at Norwegian plants producing ferroalloys indicate that in addition to emissions of CO_2 and CH_4 also N_2O is emitted. Due to the CRF, the N_2O emissions are reported in 2C7i (ferroalloys N_2O).

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_2 emissions from production of ferroalloys is defined as a key category.

4.4.2.2 Methodological issues

<u>CO_2</u>

The methods used in the calculation of CO_2 emissions form 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_2-emissions:

1. Mass balance: the emission of CO_2 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).
2. 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_2 are calculated based on the emission of CH_4 and are reported in CRF table 6.

<u>CH_4 and N_2O</u>

The emissions of CH_4 and N_2O 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_4 and N_2O.

NMVOC

The emissions are estimated by Statistics Norway from the consumption of reducing agents and an emission factor.

4.4.2.3 Activity data

CO_2

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.

Table 4-25: Ktonnes of reducing agents in the ferroalloys production for some selected years.

Activity data	1990	2000	2010	2021	2022
Coal (dry weight)	395.3	544.9	360.3	613.6	591.3
Coke (dry weight)	379.0	450.1	328.0	317.5	289.9
Electrodes	34.7	48.1	48.8	49.6	44.0
Petrol coke	8.4	12.9	7.8	0.9	2.7
Pulverised coke	0.0	0.0	9.7	3.9	8.6
Bio carbon	16.6	17.5	104.0	196.7	243.9
Total	834.0	1 073.6	858.6	1 182.2	1 190.4
Bio as% av total	2%	2%	12%	17%	21%

Source: Norwegian Environment Agency

CH_4 and N_2O

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_2

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_2/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_4 and N_2O

Measurements performed at Norwegian plants producing ferro alloys indicate emissions of N_2O in addition to CH_4. The emissions of CH_4 and N_2O 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_4 and N_2O 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_x emissions. However, the emissions of CH_4 and N_2O have also been measured.

Full scale measurements have been performed at different industrial FeSi/Si furnaces. The average CH_4 and N_2O concentrations in the ferroalloy process are with some exceptions a few ppm. For N_2O and CH_4 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_2O emissions go from around zero to more than 35 ppm. The avalanches are always short in duration. There are also increased N_2O emissions during blowing phenomenon.

The EF used in the inventory represents the longer-term average N_2O and CH_4 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_4 and N_2O from production of ferroalloys.

	Si-met			FeSi-75%			FeSi-65%		
Alloy, charging routines and temperature	Batch-charging	Sprinkle-charging[1]	Sprinkle-charging and >750°C[2]	Batch-charging	Sprinkle-charging[1]	Sprinkle-charging and >750°C[2]	Batch-charging	Sprinkle-charging[1]	Sprinkle-charging and >750°C[2]
kg CH_4 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_2O 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)

[1]Sprinkle-charging is charging intermittently every minute.

[2] 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 Uncertainty assessment and time-series consistency

The uncertainty in activity data and emission factors have been calculated to ±5% and ±7% respectively, see Annex 2. The IEF (tonne CO_2/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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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

There have been no recalculations performed for this source category this year.

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_2 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_6 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_2 and perfluorocarbons (PFCs). The emission of CO_2 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_2 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 2022 the specific PFC emissions for prebaked and Soederberg were 0.09 and 0.09 kg CO_2 equivalent, see Figure 4-5 and Table 4-28.

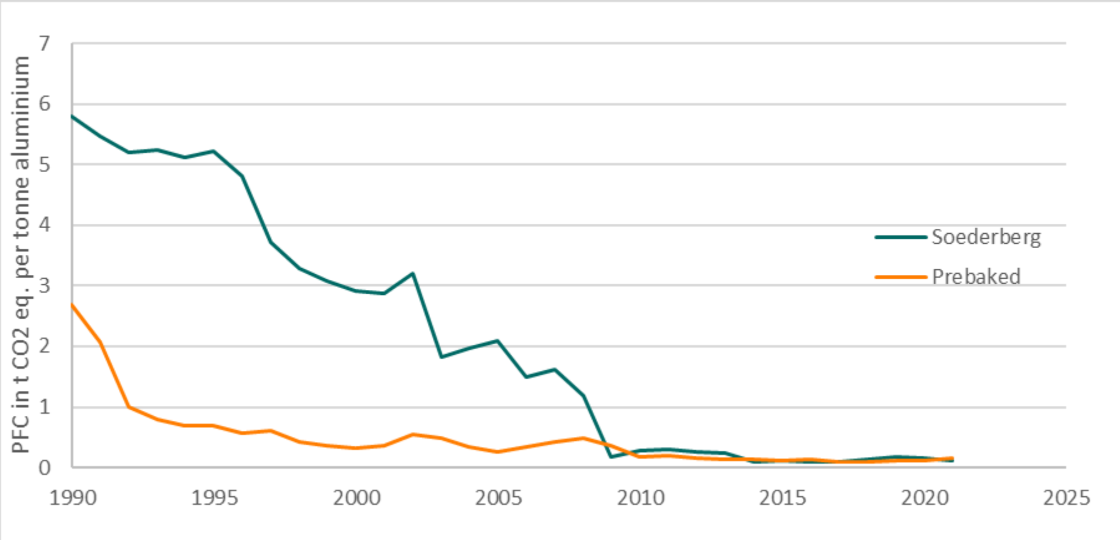


Figure 4-5: PFC in tonne CO_2 equivalent per tonne aluminium. Source: Norwegian Environment Agency.

Table 4-28: Shares of the technologies used in aluminium production and the PFC IEFs. PFC in kg CO_2 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
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
2022	6%	94%	0.09	0.09

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 94% in 2022. 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 96.5 % from 1990 to 2022 and decreased by 44.9% between 2021 and 2022. The large decrease in PFC emissions between 2021 and 2022 is because there was an increase between 2020 and 2021, primarily due to increased production at one of the plants that 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_2 equivalents in 1990 and 0.09 kg CO_2 equivalents in 2022. This is a reduction of 97.91% since 1990. An increase in production capacity is also included in the modernisation, leading to higher total emissions of CO_2. PFCs and CO_2 emissions from aluminium production are both identified as key categories.

4.4.3.2 Methodological issues

<u>CO_2</u>

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_2 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.

From 2013 and onwards, the CO_2 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.

<u>PFCs</u>

Perfluorinated hydrocarbons (PFCs), e.g., tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6), 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). 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).

Table 4-29: Technology specific slope coefficients and weight fractions for the calculation of PFCs emissions from aluminium production.

Technology [a]	**"Slope coefficient"** [b, c] **(kg $_{PFC}$/t$_{Al}$)/ (anode effect/cellday)**		**Weight fraction C_2F_6/CF_4**	
	S_{CF4}	Uncertainty (±%)	$F_{C2F6/CF4}$	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 CF_4 and C_2F_6. The mechanisms for producing emissions of PFC are the same as for producing CF_4 and C_2F_6. The two PFC gases are therefore considered together when PFC emissions are calculated. The C_2F_6 emissions are calculated as a fraction of the 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 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 (SF_6)

SF_6 used as cover gas in the aluminium industry is assumed to be inert, and SF_6 emissions are therefore assumed to be equal to consumption. At one plant 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 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 2022 is shown in Table 4-30.

Table 4-30: Mass balance for aluminium production in 2022.

Reducing agent	Amount (kt)	CO_2 emissions (kt)
Petroleum coke	254.0	895.9
Prebaked anodes	707.9	1179.3
Pitch	66.3	226.4
Coke	28.0	99.8
Soda	0.9	0.4
Anode remnant	123.6	-113.8
Waste	2.2	-2.7
Tar	0.0	-0.1
Green anodes	0.3	-1.2
Filter dust	1.2	-2.3
Graphite	0.0	0.1
Total	1 208.6	2 195.4

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_2/tonne reducing agent for the most important reducing agents in 2022 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_4 (the slope coefficients of 0.143 kg CF_4/tonne Al/anode effect minutes per cell day for CWPB and 0.092 for VSS). The amount of C_2F_6 is calculated from the Tier 2 values for CF_4, where the weight fraction of C_2F_6 to CF_4 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 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2.

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.

<u>CO_2</u>

The implied emission factor for CO_2 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_2 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_2 emissions from anode production in integrated aluminium and anode plants. For one plant, it was no longer possible to split CO_2 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_6)

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_2 and CO emissions. During the calcinations of Dolomite ($MgCa(CO_3)_2$) to magnesium oxide, CO_2 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_2. SO_2 is emitted due to the sulphur in the reducing agent used.

In the foundry, producing cast magnesium, SF_6 is used as a cover gas to prevent oxidation of magnesium. The Norwegian producers of cast magnesium has assessed whether SF_6 used 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_6 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_2 emissions from processes. During 2006 also the production of remelting Mg stopped and since then there were no emissions from this source. SF_6 emissions from magnesium foundries is defined as a key category.

4.4.4.2 Methodological issues

<u>CO_2</u>

The Norwegian emission inventory uses production data as activity data. The CO_2 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).

<u>SF_6</u>

The consumption of the cover gas SF_6 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_2. The plant reported the consumption of SF_6 to the agency.

4.4.4.4 Emission factor

An emission factor of 4.07 tonnes CO_2/tonnes produced magnesium is used to calculated the annual emissions of CO_2 (SINTEF 1998c).

4.4.4.5 Uncertainty assessment and time-series consistency

The uncertainty estimates are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a.

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, zick-alloys and aluminiumfluoride. The plant has reported process emission of CO_2 from the use of ore materials for the year 2012 and onwards.

4.4.5.2 Methodological issues

<u>CO_2</u>

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_2 emissions. However, the plant reports some process emissions of CO_2 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 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2.

4.4.6.2 Methodological issues

The emissions of CO_2 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_2 from processes are uptime in hours multiplied with an emission factor for each feedstock. When calcinations of anthracite the EF are 167 kg CO_2 per uptime hour and for petrol coke the EF is 238 kg CO_2. 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 Uncertainty assessment and time-series consistency
Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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_2 is emitted from the use of soda ash.

4.4.7.2 Methodological issues
CO_2 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_2/tonne soda ash is used for the calculations.

4.4.7.5 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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.

Source category	CO_2	Tier	Key category
2D1. Lubricants use	E	Tier 2	No
2D2. Paraffin wax use	E	Tier 1	No
2D3a. Solvent use	E	Tier 2	No
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 Occuring. IE = Included Elsewhere.

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 0.2 million tonnes CO_2 equivalents in 2022, this is 2.5% of the total emission from the IPPU-sector. The emissions from the 2D sector decreased by 19.6% from 1990 and the emissions decreased by 5.9% from 2021 to 2022.

Table 4-32: Emission trends for 2D Non-energy products from fuels and solvent use (kt CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2D1. Lubricants use	167.1	1.1 %	41.0	44.0	0.5 %	-73.7 %	7.4 %
2D2. Paraffin wax use	6.2	0.0 %	36.0	31.4	0.3 %	403.7 %	-12.7 %
2D3a. Solvent use	114.1	0.8 %	143.2	127.9	1.4 %	12.1 %	-10.6 %
2D3b. Road paving with asphalt	0.0	0.0 %	0.0	0.0	0.0 %	28.6 %	-8.8 %
2D3d. Other (use of urea)	NO	0.0 %	25.5	27.8	0.3 %	NA	9.1 %
2D. Total	287.5	1.9 %	245.7	231.2	2.5 %	-19.6 %	-5.9 %

Source: Statistics Norway and the Norwegian Environment Agency

4.5.1 Lubricant use, 2D1

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_2. Hence, the total amount of lubricants lost during their use is assumed to be fully oxidized and these emissions are directly reported as CO_2 emissions.

Emissions from waste oil handling are reported in the Energy Sector (energy recovery) and in the Waste sector (incineration).

4.5.1.2 Methodological issues

The CO_2 emissions from lubricant use are estimated by multiplying sold amounts of lubricants (m^3) by density, country specific oxidation factors, default NCV value (TJ/tonne), default C content (tonne/TJ) and the mass ratio of CO_2/C:

$$(4.11)\ Ep = Ap * d * NCV * ODUp * CC * 44/12$$

where:

E_p = CO_2 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 *NVC* 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 4-34. 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).

Table 4-33: Sold amounts of lubricants, except to foreign navigation (1.000 m^3), 1990 – 2022.

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
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
2022	0	0	0	5 368	12 596	3 065	33 109	6 099

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.

Table 4-34: Lubricant product groups in the sales of petroleum statistics.

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.

<u>Other factors</u>

The figures on sold lubricants are given in m^3 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^3/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_2 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^3/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
2022	51.2

Source: Statistics Norway

4.5.1.5 Uncertainty assessment 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 counties 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 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_2. 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_2 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:

$$(4.12) \quad Emissions = PC * PF * CCWax * 44/12$$

Where:

- Emissions = CO_2 emissions from waxes, tonne CO_2
- PC = total candle consumption, TJ
- PF = fraction of candles made of paraffin waxes
- CC_{Wax} = carbon content of paraffin wax (default), tonne C/TJ (Lower Heating Value basis)
- 44/12 = mass ratio of CO_2/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_2 emissions, using the mass ratio of CO_2/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_2/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 Uncertainty assessment 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 4 for the description of the general QA/QC procedure.

4.5.2.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

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_2, which is included in the total greenhouse gas emissions reported to UNFCCC. As explained in chapter 9, the indirect CO_2 emissions from oxidized CH_4 and NMVOC are calculated from the content of fossil carbon in the compounds. The indirect emissions of CO_2 from 2D3a are reported in the IPPU sector.

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.

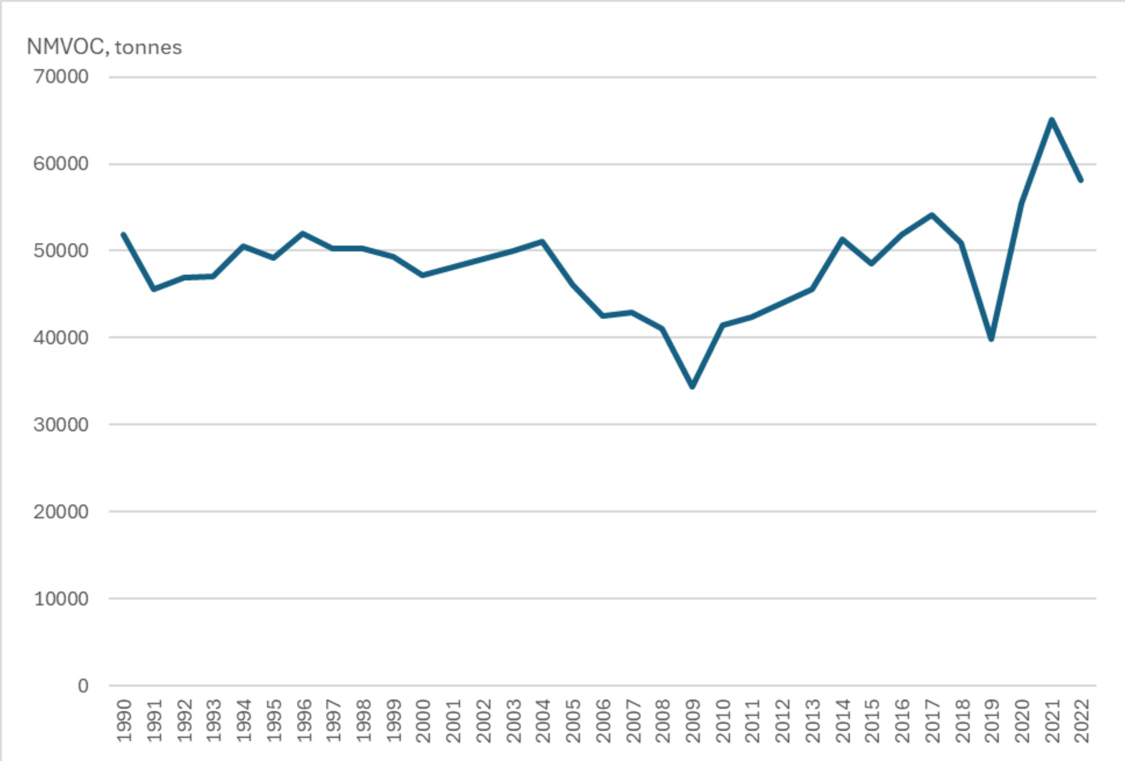


Figure 4-6: Emissions from solvent use illustrating inter-annual changes, emissions in tonnes NMVOC. Source: Statistics Norway.

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_2. 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[21]. 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.

<u>Cosmetics</u>
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 to 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 codes; (Norwegian 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.

[21] "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."

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 Uncertainty assessment 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.

<u>Uncertainty in activity data</u>
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 4. 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

There are recalculations performed for this source category this year, see chapter 10 for details.

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_2 emissions from NMVOC emissions from road paving with asphalt are reported in the IPPU sector.

4.5.4.2 Methodological issues

The emissions from road paving are calculated in accordance with a Tier 1 approach (EEA 2013).

$$E_{\text{pollutant}} = \text{AR}_{\text{production}} * EF_{\text{pollutant}}$$

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 2023).

4.5.4.5 Uncertainty assessment 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 4 for the description of the general QA/QC procedure.

4.5.4.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

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_x 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:

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$$

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:

$$\textit{Emissions} = \textit{Activity} * 12/60 * \textit{Purity} * 44/12$$

where

Emissions = CO_2 emissions form urea-based additive in catalytic converters (Gg CO_2)
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 ($CO(NH_2)_2$) to carbon (C), while 44/12 converts C to 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 CO_2.

4.5.5.5 Uncertainty assessment 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 emissions from the source category integrated circuit or semiconductor under the category 2G1, see Table 4-42.

Table 4-42: Electronics industry. Components emitted and included in the Norwegian inventory.

Source category	SF_6	HFCs	PFCs	NF3	Tier	Key category
2E1. Integrated circuit or semiconductor	IE*	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.
** Included in 2G1*

4.6.1 Integrated circuit or semiconductor, 2E1

4.6.1.1 Category description

There are SF_6 emissions from the use in the manufacturing of semiconductors, these are due to confidentiality reported in 2G1.

4.6.1.2 Methodological issues

There have been emissions of SF_6 from this source since 1995. According to a report from SFT (1999c), data on sales to semiconductor manufacturers were collected for 1998 and amounted to 90 kg. The sales for 1998 have been used for the years 1995-1998. The report projected sales to increase to 100 kg and has been assumed for the years 1999-2002. For the years 2018-2022, the two producers have provided information on the annual amounts of SF_6 purchased. For the period 2003-2017, the amounts of SF_6 used have been interpolated linearly from 2002-2018.

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 from 1995 to 1998 and 50 kg from 1999 to 2002. From 2018 and onwards, we continue to assume that 50% of the gas reacts in the etching process. One producer has not installed a scrubber and the remaining 50% is considered as emitted. Another producer has installed a scrubber that removes 96% of the SF_6 that is not assumed to reacts in the etching process. To be conservative, we calculate that 10% of the SF_6 that is not assumed to react in the etching process is emitted. For the period 2003-2017, the amounts of SF_6 emitted have been interpolated linearly from 2002-2018.

4.6.1.4 Emission factors

See chapter 4.6.1.3.

4.6.1.5 Uncertainty assessment and time series consistency

An uncertainty estimate is given in Annex 2. 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 4. There is no specific QA/QC procedure for this source category.

4.6.1.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

4.6.1.8 Category-specific planned improvements

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

4.6.2 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 4-43 and Table 4-44 for details.

Table 4-43: Product uses as substitutes for ODS. Components included in the inventory, tier of method and key category.

Source category	HFCs	PFCs	SF_6	NF_3	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, areosols 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 Occuring. IE = Included Elsewhere.

Table 4-44: Emission trends for 2F Product uses as substitutes for ODS (kt CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2F1. Refrigeration and air conditioning	0.0	0.0 %	713.1	718.7	7.7 %	1 446 640.9 %	0.8 %
2F2-2F6. Foam blowing agents, fire protection, aerosols, solvents, other applications.	NO	NA	30.1	28.0	0.3 %	NA	-6.8 %
2F. Total	0.0	0.0 %	743.2	746.8	8.0 %	1 503 091.8 %	0.5 %

Source: Statistics Norway and Norwegian Environment Agency

Table 4-44 shows the emission trends for 2F. The GHG emissions from this sector category were about 0.7 million tonnes in 2022, this is 8.0% of the total emission from the IPPU-sector. The emissions in 1990 were insignificant (49 tonnes CO_2 equivalents) but have increased substantially over the years. However, due to restrictions from the EU F-gas regulation (implemented in Norway) in combination with equipment that has reached its end of life the emissions of HFC's have declined since 2014. The emissions increased by 0.5% from 2021 to 2022. 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. In January 2003 a tax on import and production of HFC and PFC was introduced at NOK 180 per tonne CO_2 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 2024 at NOK 1 176 (approximately EUR 102) per tonne CO_2 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.

4.6.3 Refrigeration and air conditioning, 2F1

4.6.3.1 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.

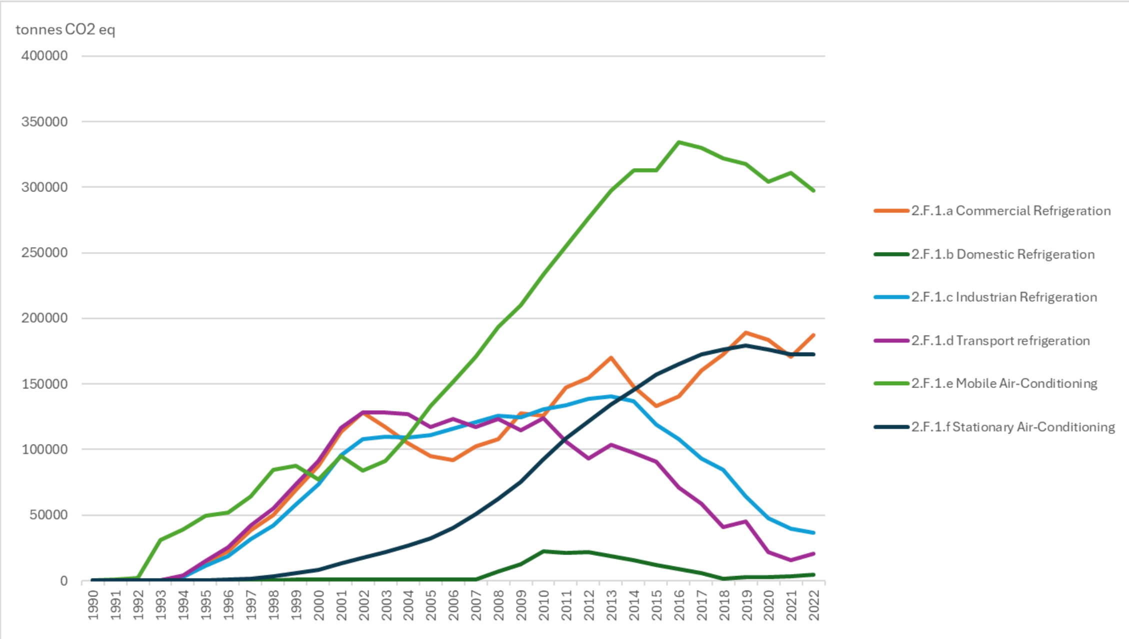


Figure 4-7: Emissions in the 2F1 sectors illustrating inter-annual changes, emissions in ktonnes CO_2 equivalents. Source: Statistics Norway.

As seen in the figure above there is a reduction in emissions in 2.F.1a in the years around 2003-2005. In the same period are the emissions from 2.F.1.d and 2.F.1.c stabilised. This development 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.

The decrease in emissions after 2016 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 reached a peak in emissions in 2014 and has had a steady reduction since.

The decline of emissions in 2F from 2019-2020 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.

4.6.3.2 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.

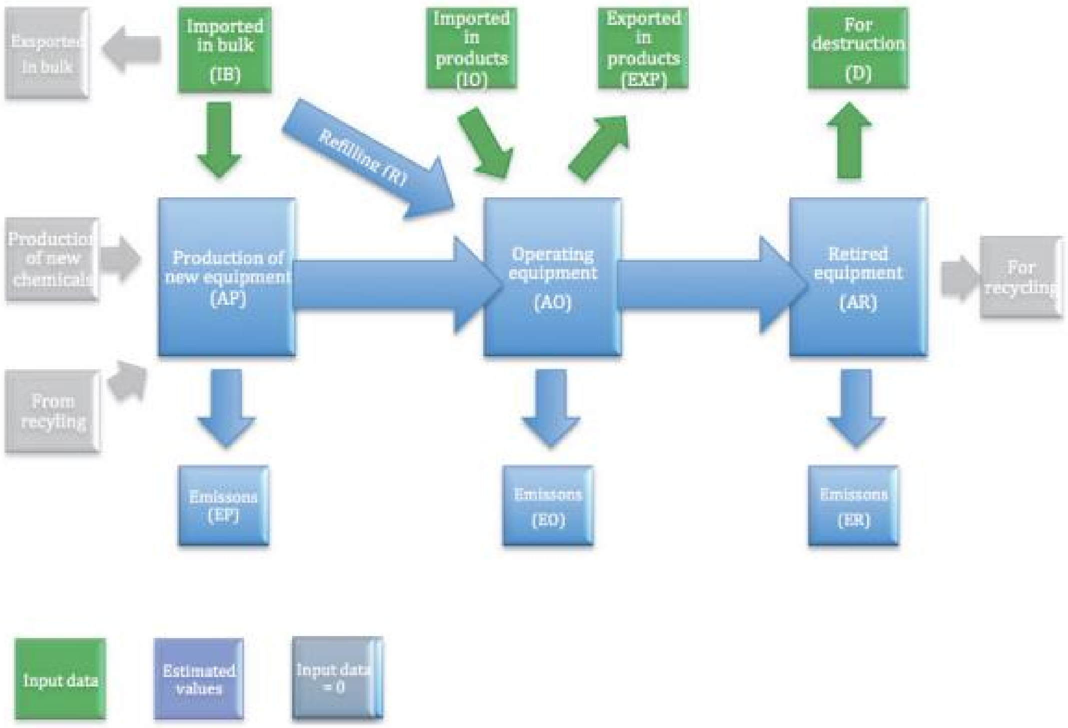


Figure 4-8: The three phases in a product's life cycle and the flow of chemicals in and out of the phases.

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
y = year
a = application

The calculation of emissions differs somewhat between the different source categories. Table 4-45 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 4-45: 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 equipment 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 4-46. The emission factors are within the range of factors recommended by the IPCC 2006 Guidelines.

$$EP_{y,a,c} = AP_{y,a,c}*EFP_a$$

EP = Emissions from production of new equipment
AP = Amount of chemical f or production of new equipment
EFP = Emission Factor (leakage rate) f 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 loose 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:	EOy,a,c = EOy-1ac+ AONy,a,c · EFOa - AONy-lt,a,c · EFOa
Mobile air conditioning (with refilling):	EOy,a,c = MAX (IBy,a,c;AOy(31.12),a,c · EFOa)
Other application categories with refilling:	EOy,a,c =AOy(31.12),a,c · EFOa

AONy,a,c = (IBy,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
lt = lifetime (years)
y = year

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).

Emissions from retired equipment

As a response to a recommendation from the ERT, Norway has improved the methodology regarding emissions from retired equipment. When an equipment reaches its end of life it is emptied for the remaining F-gas. In this process there will be some emissions. The collected gas can be sent for destruction or recycled and reused. Norway has detailed figures for the amounts of F-gas being destroyed. But as this amount is relatively low, a project to identify reuse and recycling has been completed and implemented from the 2024 submission.

Application categories with refilling: $ER_{y,a,c} = AR_{y,a,c} * EF_{eol} = AR_{y,a,c} - D - RE$
Application categories without refilling: $ER_{y,a,c} = AR_{y,a,c} - D$

$ER_{y,a,c}$ = Emissions from retired equipment
$AR_{y,a,c}$ = Amount of chemical in retired product
EF_{eol} = Emission factor for retired equipment
D = Amount of chemical collected for destruction
RE = Amount of chemical recycled
y = year
a = application
c = chemical

The amount of gas collected for recycling is used as refill and/or in new equipment.

4.6.3.3 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).

4.6.3.4 Emission factors

The emission factors used in the calculations are shown in Table 4-46.

Table 4-46: Emission factors for HFCs and PFCs from 2F1 Refrigeration and Air conditioning.*

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	NE	65
Medium/Large Commercial Refrigeration	12	2 (1990-2003) 0.5 (2004-)	10 (1990-2002) 4 (2008-)	70	80
2.F.1.b Domestic Refrigeration	15	NO	0.5	NE	92.5
2.F.1.c Industrial Refrigeration	17	2	10	90	80
2.F.1.d Transport Refrigeration	9	1	20	70	100
2.F.1.e Mobile AC	12	NO	10	50	60
2.F.1.f Stationary AC	18	1 (1990-1999) 0.2 (2000-)	4	80	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, but there are identified collection from retired equipment, hence this is subtracted from the waste.

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, see description in section 4.7.1.2 and 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, see description in section 4.7.1.2 and 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 and some gas is cleaned and reused (see description in section 4.7.1.2 and 4.7.1.3).

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, see description in section 4.7.1.2 and 4.7.1.3.

4.6.3.5 Uncertainty assessment 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 2) 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.

4.6.3.6 Category-specific QA/QC and verification

In addition to the general QA/QC procedures described in Annex 4, 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

4.6.3.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

4.6.3.8 Category-specific planned improvements

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

4.6.4 Other applications, 2F6

4.6.4.1 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.

An analysis of the category shows that more than 95% of the Norwegian emissions reported in 2F6 since 1995, in terms of CO_2 equivalents[22], are from Foam blowing agents, aerosols and fire extinguishers. For the other categories included in the aggregated 2.F.6 amount, the emitted amounts were zero or close to zero. It has been a shift between the

[22] Note that the reported emissions in sector 2F6 are given in CO_2 eq.

subsectors in the last years, and emissions from metered dose inhalers (included in 2.F.4) has become of larger.

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_2 equivalents before 1998, 2.3 - 4.4 kg CO_2 equivalents in the period 1998 to 2012 and 1.3 - 4.4 kg CO_2 equivalents in the period 2013 - 2021. Per capita emissions in comparable countries were in the range of 0 - 11.71 kg CO_2 equivalents in 2012. For HFC-152a the per capita emissions were in the range of 0 - 0.8 kg CO_2 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_2 equivalents in 2012.

Areosol (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_2 equivalents per capita before 2000, to 3.5 - 4.4 kg CO_2 equivalents per capita in the period 2001 - 2017. The amounts are decreasing and rapidly reduced after 2018. Per capita emissions in comparable countries were in the range of 0.24 - 12.91 kg CO_2 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_2 equivalents per capita before 2011, to a stable level in the range 2.1 - 3.0 kg CO_2 equivalents per capita in the period 2011 - 2021. Comparable countries had emissions in the range of 0.59 - 6.78 kg CO_2 equivalents per capita in 2012.

The Norwegian per capita emission for each of these three sectors in 2012 was well within the range of the selected comparable countries.

Table 4-47 below shows the per capita reported emissions in 2020 for 2F2-2F6 for the same countries as in the 2012 analysis. Norway is within the range of these countries.

Table 4-47: Per capita emissions for 2F2-2F6, 2020.

Country	Per capita emissions (tonnes CO_2 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

4.6.4.2 Methodological issues

See description for source category 2F1.

4.6.4.3 Activity data

See description for source category 2F1.

4.6.4.4 Emission factors

Leakage rates and product lifetimes used in the calculations are shown in Table 4-48.

Table 4-48: 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)*

4.6.4.5 Uncertainty assessment and time series consistency

See description for source category 2F1.

4.6.4.6 Category-specific QA/QC and verification

See description for source category 2F1.

4.6.4.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

4.6.4.8 Category-specific planned improvements

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

4.7 Other product manufacture and use – 2G

Norway reports the source categories electric equipment, SF_6 and PFCs from other product use, medical applications, propellant for pressure and aerosol cans and other use of N_2O under the category 2G, see Table 4-49.

Table 4-49: Other product manufacture and use. Components included in the inventory, tier of method and key category.

Source category	HFCs	PFCs	SF_6	NF3	N_2O	Tier	Key category
2G1.Electric equipment	NO	NO	E*	NO	NA	Tier 2	No
2G2. SF_6 and PFCs from other product use	NA	NO	E	NO	NA	Tier 1	No
2G3a. Use of N_2O 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 N_2O	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
** Includes SF_6 from the use in the manufacturing of semiconductors previously reported in 2E1*

Table 4-50 shows the emission trends for 2G as a whole and for the various sub-categories. The GHG emissions from this sector category were about 85 kt CO_2 equivalents in 2022, this is 0.9% of the total emission from the IPPU-sector. The emissions from this sector are stable compared to the 1990 level have decreased by 0.2% from 2021 to 2022.

Table 4-50: Emission trends for 2G Other product manufacture and use (t CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2G1.Electric equipment	52.7	0.4 %	44.6	43.9	0.5 %	-16.8 %	-1.8 %
2G2. SF_6 and PFCs from other product use	2.3	0.0 %	27.3	27.1	0.3 %	1075.7 %	-0.9 %
2G3a. Use of N_2O in anaesthesia	30.4	0.2 %	11.9	12.7	0.1 %	-58.1 %	7.2 %
2G3b1. Propellant for pressure and aerosol products	NO	NA	1.4	1.4	0.0 %	NA	0.0 %
2G3b2. Other use of N_2O	NO	NA	0.4	0.4	0.0 %	NA	0.0 %
2G. Total	85.4	0.6 %	85.6	85.4	0.9 %	0.0 %	-0.2 %

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 (NF3). Our assessment is that here are no emissions of NF3 in Norway.

4.7.1 Electric equipment, 2G1

4.7.1.1 Category description

SF_6 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_6 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.

Emissions of SF_6 from the use in the manufacturing of semiconductors previously reported in 2E1 are due to confidentiality now reported in 2G1.

4.7.1.2 Methodological issues

The general methodology for estimating SF_6 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_6. 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_6use 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_6 have been made upon the information in SFT report (SFT 1999c). The emissions are calculated with emission factors from Table 4-52.

From 2003 and onwards the reporting group of users of SF_6 in electrical equipment have reported detailed figures on the amounts in stock, reuse, destructed, 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 4-51.

Table 4-51: Share of users of SF_6 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).

4.7.1.3 Activity data

Data is collected from companies that use SF_6 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.

4.7.1.4 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 4-52.

Table 4-52: Leakage rates from products containing SF_6, %.

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
2022	0.35	0.18

Source: SFT (1999c), Statistics Norway

4.7.1.5 Uncertainty assessment and time series consistency

An uncertainty estimate is given in Annex 2. The uncertainty has been revised in the 2022 reporting. The uncertainty of 10% for the activity data and 60% 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.

4.7.1.6 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.

4.7.1.7 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

4.7.1.8 Category-specific planned improvements

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

4.7.2 SF_6 and PFC from other product use, 2G2

4.7.2.1 Category description

This source category includes SF_6 emissions from other product use.

4.7.2.2 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_6 in the products, and from production of windows. Footwear with SF_6 was imported, and the use ended in 2001. There was no production of sound-insulting 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_6 in those windows is reported as emitted.

4.7.2.3 Activity data

Data is collected from direct consultations with importers and exporters of bulk chemicals and products containing SF_6. The activity data are annual additions of SF_6 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.

4.7.2.4 Emission factors

Leakage rates and product lifetimes used in the calculations are shown in Table 4-53 and Table 4-54.

Table 4-53: Yearly rate of leakage of SF_6 from different processes.

Emission source	Leakage rate (% of input of SF_6)
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)

Table 4-54: Product lifetimes and leakage rates from products containing SF_6.

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)

4.7.2.5 Uncertainty assessment and time series consistency

An uncertainty estimate is given in Annex 2. 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.

4.7.2.6 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).

4.7.2.7 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.

4.7.3 Use of N_2O in anaesthesia, 2G3a

4.7.3.1 Category description

N_2O is used in anaesthesia procedures in hospitals, by dentists and by veterinarians.

4.7.3.2 Methodological issues

N_2O is used in anaesthesia procedures and will lead to emissions of N_2O. For the year 1998 and annually from 2000, the emissions are given by data on sales of N_2O for medical uses from the three major producers and importers in Norway. The data include N_2O 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_2O is assumed used by dentists and veterinarians as the amounts they used in 2000 were very small.

4.7.3.3 Activity data

For this source actual sale of N_2O 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.

4.7.3.4 Emission factors

The figures are based on sales of N_2O.

4.7.3.5 Uncertainty assessment 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.

4.7.3.6 Category-specific QA/QC and verification

There is no source specific QA/QC procedure for this sector.

4.7.3.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

4.7.3.8 Category-specific planned improvements

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

4.7.4 Propellant for pressure and aerosol products, 2G3b.1.

4.7.4.1 Category description

N_2O is used as a propellant in spray boxes and this use will lead to emissions of N_2O. It is also used in research work, for instance in the food industry and at universities. There is no production of N_2O for these purposes in Norway.

4.7.4.2 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.

4.7.4.3 Activity data

Information has been gathered from the plants indicating that there is no production or sale of N_2O for use as a propellant in Norway. The N_2O 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.

4.7.4.4 Emission factors

Not relevant.

4.7.4.5 Uncertainty assessment 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.

4.7.4.6 Category-specific QA/QC and verification

There is no source specific QA/QC procedure for this sector.

4.7.4.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

4.7.4.8 Category-specific planned improvements

During 2024, there will be a project that analyses the import of cans containing N_2O.

4.7.5 Other use of N_2O, 2G3b.2

4.7.5.1 Category description

Small amounts of N_2O are used for research work and for drag-racing.
There were no emissions of N_2O from use in research and for drag racing in 1990. The use has been estimated to 407 tonnes CO_2 equivalents from the year 1993 and onwards.

4.7.5.2 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.

4.7.5.3 Activity data

Data on imported amounts in 2002 has been used for all years.

4.7.5.4 Emission factors

Not relevant.

4.7.5.5 Uncertainty assessment 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.

4.7.5.6 Category-specific QA/QC and verification

There is no source specific QA/QC procedure for this sector.

4.7.5.7 Category-specific recalculations

There have been no recalculations performed for this source category this year.

4.7.5.8 Category-specific planned improvements

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

4.8 Other – 2H

Under Other production, Norway reports the two source categories pulp and paper and food and beverages industry, see Table 4-55.

Table 4-55: Other production. Components included in the inventory, tier of method and key category.

Source category	CO_2	NMVOC	Tier	Key category
2H1. Pulp and paper	R	NA	Tier 2	No
2H2. Food and beverages industry	R	E	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 4-56 shows the emission trends for 2H as a whole and for the various sub-categories. The GHG emissions from this sector category were 106 kt CO_2 equivalents in 2022, this is 1.1% of the total emission from the IPPU-sector. The emissions from this sector increased by 239.3% from 1990 and the emissions decreased by 5.8% from 2021 to 2022.

Table 4-56: Emission trends for 2H Other (kt CO_2 equivalents).

Source category	1990	1990, % of IPPU	2021	2022	2022, % of IPPU	Trend 1990-2022 (%)	Trend 2021-2022 (%)
2H1. Pulp and paper	10.5	0.1 %	9.2	9.0	0.1 %	-14.5 %	-2.2 %
2H2. Food and beverages industry	20.8	0.1 %	103.5	97.1	1.0 %	367.3 %	-6.2 %
2H. Total	31.3	0.2 %	112.7	106.1	1.1 %	239.3 %	-5.8 %

Source: Statistics Norway and Norwegian Environment Agency

4.8.1 Pulp and paper, 2H1

4.8.1.1 Category description

There are CO_2 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.

4.8.1.2 Methodological issues

The CO_2 emissions are calculated by multiplying the amount of limestone by an emission factor.

4.8.1.3 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(I). A-Hs2 and are shown in Table 4-5 for some selected years in the time series.

4.8.1.4 Emission factors

The emission factor used in the calculation is 0.44 tonne CO_2 per tonne limestone.

4.8.1.5 Uncertainty assessment and time-series consistency

Uncertainty estimates are given in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a. 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.

4.8.1.7 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 Food and beverages industry, 2H2

4.8.2.1 Category description

This source category includes CO_2 from carbonic acid mainly used in breweries, domestic use of captured CO_2, imported CO_2 and CO_2 from production of bio protein.

Some CO_2 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_2 bound in products and imported CO_2. 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_2 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.

4.8.2.2 Methodological issues

For carbonic acid, the CO_2 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_2 and these are included in the national inventory.

4.8.2.3 Activity data

For carbonic acid, the CO_2 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 4-57.

Table 4-57: Sold CO_2 (minus exports), imported CO_2 and domestic use (ktonnes).

Year	Sold CO_2 (minus exports)	Imported CO_2	Domestic use of CO_2 (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
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
2022	75.9	21.2	97.1

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.

4.8.2.4 Emission factors

The activity data for carbonic acid is CO_2, so emission factors are not relevant.

4.8.2.5 Uncertainty assessment and time-series consistency

See the uncertainty in the activity data for the ammonia plant (2B1) in Annex 2. 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 specific QA/QC carried out for Industrial processes is described in Annex 5a.

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.

5. Agriculture (CRF sector 3)

5.1 Overview of sector

About 9.5% of the total Norwegian emissions of greenhouse gases (GHG) originated from agriculture in 2022. This corresponds to 4.64 million tonnes CO_2 eq. Emissions from agriculture were in 2022 about 7% lower than in 1990, and about 2% lower than in 2021.

The sector's largest sources of GHG's were enteric fermentation (CH_4) from domestic animals contributing with 52% of the sector's emissions, and N_2O from agricultural soils contributing with 33%. Manure management contributed about 12%. CO_2 emissions in the agriculture sector, mainly from liming and a minor part from urea application, contributed with 3%. Minor emissions of the greenhouse gases N_2O and CH_4 arising from the burning of crop residues on fields also occurred.

Table 5-1: Emissions from Agriculture categories in 1990, 2021 and 2022 (ktonnes CO_2 equivalents).

Category	1990	1990, % of Agriculture	2021	2022	2022, % of Agriculture	Trend 1990-2022 (%)	Trend 2021-2022 (%)
3A Enteric fermentation	2573	52%	2454	2418	52%	-6%	-1%
3B Manure management	524	11%	568	557	12%	6%	-2%
3D Agricultural soils	1 613	32%	1 602	1 542	33%	-4%	-4%
3F Field burning of agricultural residues	38	1%	4	4	0%	-88%	18%
3G Liming	231	5%	122	122	3%	-47%	0%
3H Urea application	1	0%	0	0	0%	-69%	70%
Total	4 979	100%	4 750	4 643	100%	-7%	-2%

Source: Statistics Norway and the Norwegian Environment Agency

Agriculture contributes particularly to CH_4, N_2O and NH_3 emissions. Domestic animals are the major source of CH_4 emissions from agriculture. Both enteric fermentation and manure management contribute to emissions of CH_4. Manure management also generates emissions of N_2O.

Microbiological processes in the soil lead to emissions of N_2O. Both direct and indirect N_2O from soil processes are described in the IPCC methodology and are included in the Norwegian inventory. Direct N_2O 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_2O 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_3) and NO_X that gives indirect N_2O from atmospheric deposition. NH_3 volatilized from grazing animals are also included in the estimations of indirect N_2O.

As indicated in chapter 1.5, the Approach 2 key category analysis performed in 2024 for the years 1990 and 2022 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.

Table 5-2: Key categories in the sector Agriculture.

IPCC	Source category	Gas	Identification criteria	Method
3A1	Enteric fermentation – Cattle	CH_4	Level approach 1, level and trend approach 2	Tier 2
3A2	Enteric fermentation – Sheep	CH_4	Level approach 1 and 2	Tier 2
3A4	Enteric fermentation – Other	CH_4	Level approach 2	Tier 1
3B1	Manure management – Cattle	CH_4	Level approach 2	Tier 2
3B	Manure management	N_2O	Level approach 2	Tier 2
3Da1	Direct emissions from managed soils – Inorganic N fertilizers	N_2O	Level approach 1 and 2	Tier 1
3Da2	Direct emissions from managed soils – Organic N fertilizers	N_2O	Level approach 2	Tier 1
3Da4	Direct emissions from managed soils – Crop residues	N_2O	Level approach 2	Tier 1
3Da6	Direct emissions from managed soils – Cultivation of organic soils	N_2O	Level approach 2	Tier 1
3Db2	Indirect emissions from managed soils – Nitrogen leaching and run-off	N_2O	Level approach 2	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 5b, table A5b-1 and A5b-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, poultry for egg production and beef cows), statistics of approved carcasses (animals for slaughter and pig categories) and the Cow Recording System at TINE BA[23] (TINE BA Annually) (heifers for breeding and dairy cows). These sources cover 85-100% 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.

Table 5-3: Estimated coverage (%) of animal populations in the data sources used.

	Statistics Norway, production subsidies	Statistics Norway, statistics of approved carcasses [4]	TINE	Other
Dairy cows		100[2]	97.0[1]	
Replacement heifers			97.4[1]	
Young cattle for slaughter		100	100[3]	
Beef cows	99.8	100[2]		
Sheep	99.8	100		
Goats	100			
Laying hens	100			
Chics for breeding	100			
Chicken for slaughter		100		
Other poultry for breeding	96.5			
Other poultry for slaughter		100		
Sows		100		
Young pigs for breeding		100		
Pigs for slaughter		100		
Horses	Unknown [5]			Unkown[5]
Fur-bearing animals	100			
Deer	100			

[23] 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.

Reindeer				100[6]

Source: Estimations by Statistics Norway and the Cow Recording System (dairy cows and heifers).

[1] Share of livestock herds.
[2] Data source only for slaughter weight
[3] Data source only for slaughter age
[4] Figure refers to share of slaughtered animals, excluding home slaughter. Animals dead from other causes also excluded
[5] 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 NIBIO and Nasjonalt hesteregister.
[6] 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. In this 2024 submission a new methodology for calculating the number of pigs (animal years) is introduced. The basis is the number of slaughtered pigs per year and the other pig-categories; sows, young pigs for breeding (gilts) and weaners (piglets) are derived from that number based on how long an animal lives in the different phases. This methodology is a result of a project from NIBIO and the swine production corporation Norsvin SA[24] ((Bonesmo & Gjerlaug-Enger 2022). Activity data is provided by Norsvin SA. The whole series was revised and led to 24% lower animal number per year compared to former estimation.

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 daily milk production and amount 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.*[25]).

[24] Norsvin SA is the research and sales organization of swine genetics in Norway.
[25] Moen, O. (*annually*): Personal information, email from Oddvar Moen, Tine Rådgivning annually.

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:

1. 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.
2. 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.
3. Counting the number of animals slaughtered gives a very precise value of the number of animals.
4. 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.

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)). 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[1]	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
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
2022	230 862	44 258	245 335	109 517	189 099

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*[26]).

[26] UMB (2001): Expert judgement by Department of Animal Science, Ås: Norwegian University of Life Sciences.

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)[27]. 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:

- 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_2 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

[27] Former named the Agricultural Economics Research Institute (NILF).

nitrogen. Of the nitrogen compounds emitted to air from animal manure, N_2O, NO_X and NH_3 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:

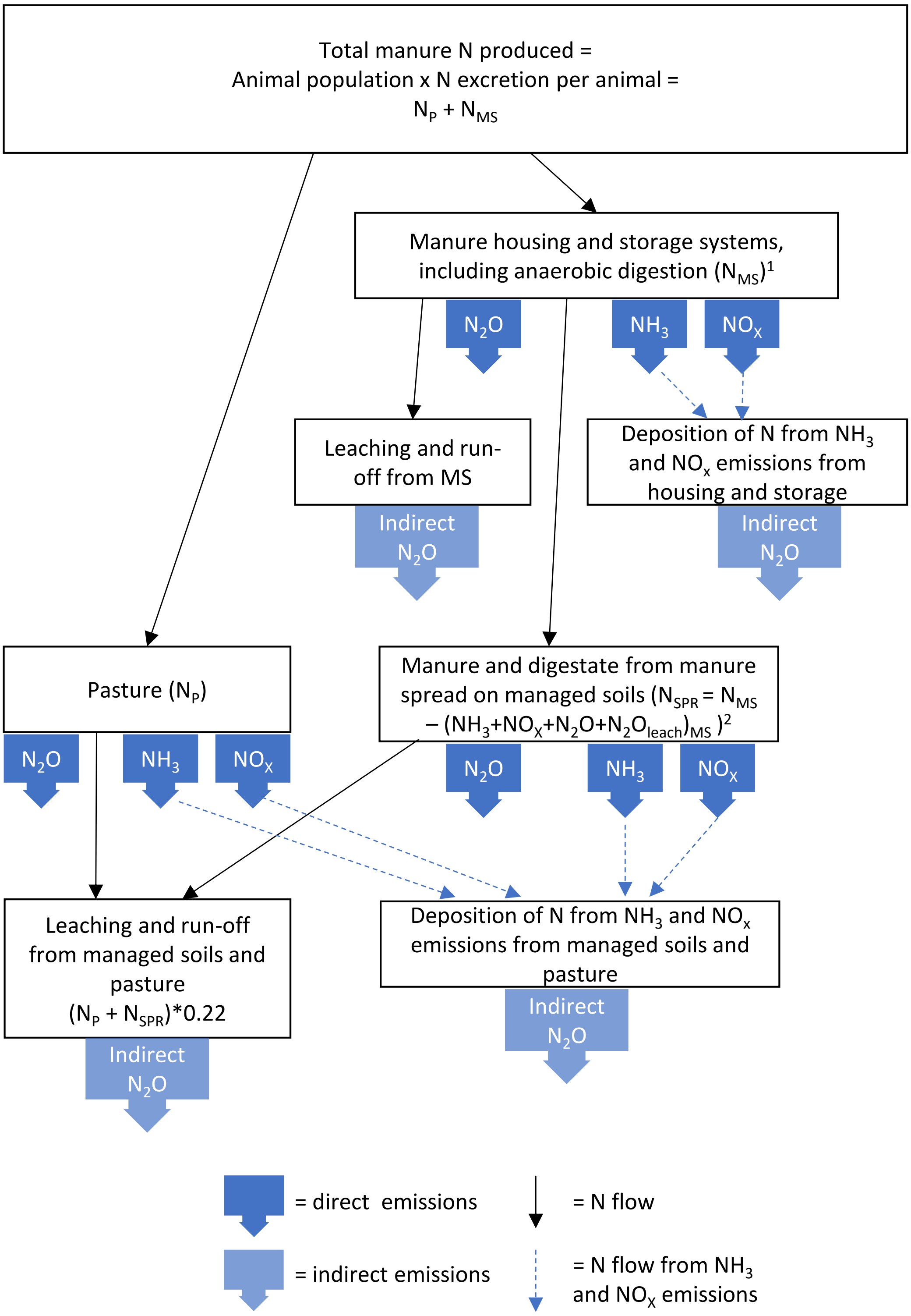
1. Manure management systems (N_2O, NH_3 and NO_X)
2. Application of manure on soil (N_2O, NH_3 and NO_X)
3. Droppings from animals on pastures (N_2O, NH_3 and NO_X)
4. Leakage of nitrogen through manure management systems and soils (N_2O)
5. Deposition of nitrogen from emissions of NH_3 and NO_X (N_2O)

Though the nitrogen flow depends continuously 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; EEA 2023). 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).
- N_2O 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 N_2O, NH_3 and NO_X in manure housing and storage is deducted. However, N lost as N_2O, NH_3 and NO_X during spreading, as well as indirect emissions of N_2O due to atmospheric deposition, are not deducted.
- 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 N_2O, NH_3 and NO_X in manure housing and storage. NO_X emitted during and after spreading of manure also has the same basis. For NH_3 emissions, N lost as N_2O and NO_X during spreading, as well as indirect emissions of N_2O due to atmospheric deposition is not deducted. Similarly, for NO_X emissions, N lost as N_2O and NH_3 during spreading, as well as indirect emissions of N_2O due to atmospheric deposition is not deducted.

- Emissions of N_2O, NH_3 and NO_X from pasture are calculated independently of each other and are based on the amounts of N (or TAN for NH_3 emissions) estimated in manure dropped during grazing.
- N_2O 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 N_2O, NH_3 and NO_X in manure housing and storage. N_2O lost through leaching due to grazing is based on total N excreted on pastures. N_2O 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 NH_3 from housing is not deducted.
- The nitrogen in NH_3 and NO_X volatilized during housing, storage, pasture and spreading of manure is the basis for the calculation of N_2O 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.



[1] 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.
[2] Emissions of N_2O, NH_3 and NO_X that have occured 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[28]. 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_2 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_4)

5.2.1 Category description

An important end product from ruminal fermentation is methane (CH_4). The amount of CH_4 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 the IPCC, the method for estimating CH_4 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_4 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 2418 ktonnes CO_2 equivalents in 2022, which is 52 percent of the GHG emissions from this sector. Emissions decreased by 6% in the period 1990-2022 and decreased by 1.4% in 2021-2022.

5.2.1.1 Methodological issues

A Tier 2 methodology is used for calculating CH_4 from enteric fermentation for the main emission sources cattle and sheep.

[28]https://www.regjeringen.no/contentassets/0f1af0ca7efe493e8e48b46b6fba5ffd/rapport-tbu-jordbruk_siste.pdf

The following basic equation is used to calculate the enteric CH_4 emission factor for non-dairy cattle (IPCC 2006):

$$\mathrm{EF} = (\mathrm{GE} \times Y_m \times 365\ \mathrm{days/yr})\ /\ 55.65\ \mathrm{MJ/kg}\ CH_4$$

Where:

EF = emission factor, kg CH_4/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 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.

In the 2024 submission the methodology for calculating CH_4 emissions from enteric fermentation from dairy cows has been updated. Previously, the CH_4 emission factor was calculated using the same equation as for the other cattle categories, using values for GE and Ym based on annual figures for milk yield and percentage of concentrate feed in the diet. In the 2024 submission the CH_4 emission factor now takes into account the period of the year in which milk cows do not lactate (60 days typically), where methane emissions during the lactation period are calculated based on annual figures for milk yield, amount of concentrate feed in diet (as opposed to percentage in the previous calculation), and crude fat in the total diet. Methane emissions during the dry period where no lactation occurs are calculated with a fixed coefficient. The final emission factor for the whole year is therefore calculated as follows:

$$\mathrm{EF, kg}\ CH_4\ /\ \mathrm{animal/yr} = (\mathrm{GEI\ x\ 305} + 12.6\ \mathrm{x}\ 60)\ /\ 55.65\ \mathrm{MJ/kg}\ CH_4$$

Where:

GEI , MJ CH_4/animal/day (lactation period) = 12.89 + 0.243 x EKM + 0.665 x CF – 0.0504 x Fat

Where:

EKM = Energy-corrected milk, kg per animal per day

CF = Concentrate feed in diet, kg per animal per day

Fat = Crude fat in diet, g per kg concentrate feed per day

The terms GE and Ym as used for the other cattle categories can also be derived from the new equation:

$$\text{GE, whole year} = (\text{GEL x } 305 + 135.8 \text{ x } 60) \div 365$$

Where:

$$\text{GEL, GE, lactation period} \ = \ 135.82 \ + \ 4.31 \text{ x EKM} \ + 14.51 \text{ x CF} - \ 0.234 \text{ x Fat}$$

$$Ym \ = \ 100 \ x \ GEI \ \div \ GE$$

This change in methodology was made in order to better reflect Norwegian agricultural practices and emission reduction measures. Emissions from dairy cows that are not lactating are lower than during the lactation period due to lower feed uptake – therefore, switching the milk yield variable from yearly to daily yield and explicitly accounting for non-lactating days in the year can account for this effect. Furthermore, the use of higher quality silage also reduces emissions, however reliable sources of its use on a national level are unavailable. The new equation therefore accounts for improved silage indirectly by including the amount of feed concentrate and energy corrected milk yield, as it is assumed that higher milk yield with the same or lower level of concentrate feed in the diet is due to higher quality silage, and therefore lower emissions. Finally, fat in the diet was included, as it has been shown that it has a reducing effect on emissions. A more detailed description of the new methodology is found in the report by Volden et al. (2023).

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. For goats, CH_4 from enteric fermentation is estimated using the Tier 1 method from the 2019 refinement to the 2006 IPCC Guidelines (IPCC 2019). The methodology for calculating CH_4 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_4 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 5b.

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, information for milk yield and the amount of concentrate feed and fat in the diet is required.

Data for milk yield and amount of concentrate feed is obtained from the cow recording system at the dairy and agricultural data company Mimiro[29], while data for amount of crude fat in the diet based on data obtained from the feed ration program NorFor[30]. While data is limited on the amount of crude fat in the diet, it is assumed that it has increased since 1990, so values are calculated using linear interpolation, from 40 g/kg concentrate feed in 1990 to 55 g/kg concentrate feed in 2022.

[29] Reported data from Mimiro via Altinn, www.mimiro.no

[30] Personal communication, NorFor

Table 5-6: Important parameter inputs in the calculations of GE and Ym for dairy cows.

	Daily milk production. dairy cows. kg/animal/day	Amount of feed concentrate in the rations of mature dairy cows, kg	Amount of crude fat in rations of mature dairy cows, g/kg concentrate
1990	20.76	4.82	40.00
1995	20.75	5.03	42.34
2000	20.22	4.99	44.69
2005	22.08	5.31	47.03
2010	24.18	6.24	49.38
2013	25.38	6.85	50.78
2014	25.96	7.19	51.25
2015	26.71	7.14	51.72
2016	27.05	6.99	52.19
2017	27.61	7.11	52.66
2018	27.47	7.58	53.13
2019	28.20	7.54	53.59
2020	28.35	7.57	54.06
2021	28.44	7.60	54.53
2022	27.86	7.44	55.00

Sources: Cow Recording System (Mimiro Annually), NorFor

Further discussion of the values are given in the report by Volden et al. (2023).

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_4 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_4 conversion rate, Y_m, was adjusted to account for the digestibility of the dietary dry matter (DE):

$$Y_m = 0.1058 - 0.0006 \times \mathrm{DE}$$

Based on this information an average GE and Y_m factor for Norwegian beef cows was estimated.

Table 5-7: Norwegian values for GE and Ym for beef cows.

GE intake MJ/day	$Y_{m\%}$	Methane kg per head and year
194	6.82	86

Source: Aspeholen 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:

$$CH_4(\text{GE Mcal/day}) = -0.056 + 0.0447 \times \text{GEI} + 0.0039 \times \text{NDF} - 0.033 \times \text{EE} + 0.00141 \times \text{BW}$$

$$\begin{aligned} \text{GEI} &= \text{gross energy intake (Mcal/day)} \\ \text{NDF} &= \text{neutral} - \text{detergent fiber, percent in diet, DM basis} \\ \text{EE} &= \text{ether extract, percent in diet, DM basis} \\ \text{BW} &= \text{body weight, kg} \end{aligned}$$

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:

Slaughtered < 1 year: GE = 38.95 + 1.0558 × CAW – 6.96 × SLA

Slaughtered > 1 year: GE = 112.99 + 0.3495 × CAW – 4.696 × 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 × CAW + 0.1465 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 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
2010	221	22.8	302	18.0
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	18.1
2022	230	19.2	321	18.2

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. Carcass weight	Heifers < 1 year. Average age, months	Bulls < 1 year. Carcass weight	Bulls < 1 year. 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
2010	93	8.1	116.1	7.5
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
2022	113	8.5	133.1	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 2024, Annex 5b 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. 2022.

	Carcass weight. kg	Age at slaughter. Months	Conversion factor for methane, Ym.%
Breeding sheep > 1 year	32	NA	6.5
Breeding sheep < 1 year	31	12	4.5
Lamb for slaughter, Jan.-May	20.03	11	4.5
Lamb for slaughter, June-Dec.	19.34	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. Ym 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_m 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_m used in the estimations for sheep are given in NIR 2024 Annex 5b, 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). For goats, the IPCC default emission factor from 2019 refinement is used (IPCC 2019). 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.

Pigs

In former submissions enteric methane from pigs has been estimated with a Tier 1 method with one factor for all swine categories (IPCC 2006). In the 2024 submission this was updated with a Tier 2 method. The change in methodology led to recalculation which is described more closely in chapter 10 Recalculations.

The new method is based on a project from 2021 by NIBIO and Norsvin SA[31] (Bonesmo, H. and Enger, E. G. (2021). The swine population is divided into five different categories: piglets (weaners), young pigs for breeding (gilts), pigs for slaughter (finishers), sows and boars. The animal numbers are estimated as described in section 5.1.1. Livestock population characterisation.

Emission factors are calculated for each group based on the equations developed by Philippe and Nicks (2015). The emission factors are derived from daily digestible residues intake (Daily dRes intake). Input data required for this estimation, as *daily energy intake FU*, expressed in feed units (FU) and *Daily live weight (LW) ga*in, is collected from Ingris, the data collecting system for swine producers. The following equations were developed to predict daily rate methane per animal and day:

Daily rate CH_4 per (animal and day) = Daily dRes intake g x dRes factor
Daily dRes intake = dRes percentage feed x Daily energy intake FU / FU concentration feed
Daily energy intake FU = Daily LW gain x FU per kg Daily LW gain
Data sources:
dRes factor, Philippe and Nicks (2015)
dRes percentage feed, typical numbers form Norwegian feed producers
FU concentration feed, typical numbers form Norwegian feed producers
Daily LW gain, Ingris, the Norwegian Meat and Poultry research Centre
FU per kg Daily LW gain, Ingris, the Norwegian Meat and Poultry research Centre
The emission factors for pigs in 2022 are shown in Table 5-11.

Table 5-11: Emission factors for CH_4 from enteric fermentation from pigs in 2022.

Animal	Emission factor 2022 (Tonnes CH_4/animal/year)
Piglets 4-10 weeks	0.0003
Young pigs for breeding	0.0009
Pigs for slaughter, animal places	0.0013
Sows	0.0036
Boar	0.0029

For the other animal categories, the Tier 1 default emission factors for each kind of animal are used. The factors used are shown in Table 5-12.

[31] Norsvin SA is a Norwegian swine production corporation.

Table 5-12: Emission factors for CH_4 from enteric fermentation and different animal types estimated with the Tier 1 method.

Animal	Emission factor (Tonnes/animal/year)	Source
Horses	0.018	(IPCC 2006)
Goats	0.009	(IPCC 2019)
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), IPCC (2019), Karlengen et al. (2012), Svihus (2015).

5.2.2 Uncertainty assessment and time-series consistency

5.2.2.1 Activity data

The data is considered to be known within ±5% for animal population except for pigs where ± 7 is considered (Expert judgment, Statistics Norway 2024). 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, sheep, and pigs where a tier 2 methodology is used.

The standard deviation of the emission factors is considered to be ±40%, which is the estimate from the IPCC guidelines (IPCC 2006). An uncertainty estimate of ±27.6% for dairy cows (Volden et al. 2023), ±20% for beef cows and pigs (IPCC 2006) and ±25 for other cattle and sheep in the Tier 2 methodology (Storlien & Harstad 2015).

5.2.3 Category-specific QA/QC and verification

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.

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).

The Norwegian University of Life sciences has further investigated and documented the national emission factor of 20 g CH_4 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_4 per year. Total emissions were 98 tonnes in 2015, which shows this an insignificant source of CH_4 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.

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).

5.2.4 Category-specific recalculations

There are recalculations performed for this source category this year for dairy cattle, pigs and goats, and chapter 10 gives more details.

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_4 and N_2O)

5.3.1 Category description

The relevant greenhouse gases emitted from this source category are CH_4 (IPCC 3Ba) and N_2O (IPCC 3Bb). Emissions from cattle are most important in Norway for both components. Both CH_4 emissions from cattle manure management and N_2O emissions from manure management are key category according to the Approach 2 key category analysis.

CH_4 emissions due to manure management amounted to 395 ktonnes CO_2 equivalents in 2022 whilst N_2O emissions amounted to 162 ktonnes CO_2 equivalents.

Manure management emitted 557 ktonnes of CO_2 equivalents in 2022, which are approximately 12% of the GHG emissions from agriculture.

Emissions of GHGs from manure management increased by 6.1% in the period 1990-2022 and decreased by 2% from 2021 to 2022.

Organic material in manure is transformed to CH_4 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_2O. The fraction converted to N_2O 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 N_2O (atmospheric deposition and leaching) from manure storage are also estimated.

Emissions of 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 NH_3 volatilisation from manure are used. Like for NH_3, emissions of NO_X from animal manure led to indirect emissions of N_2O from deposition. The amounts of N from 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 CH_4

Emissions of methane are estimated using a model based on a stepwise approach which is illustrated in *Figure 5.2*.

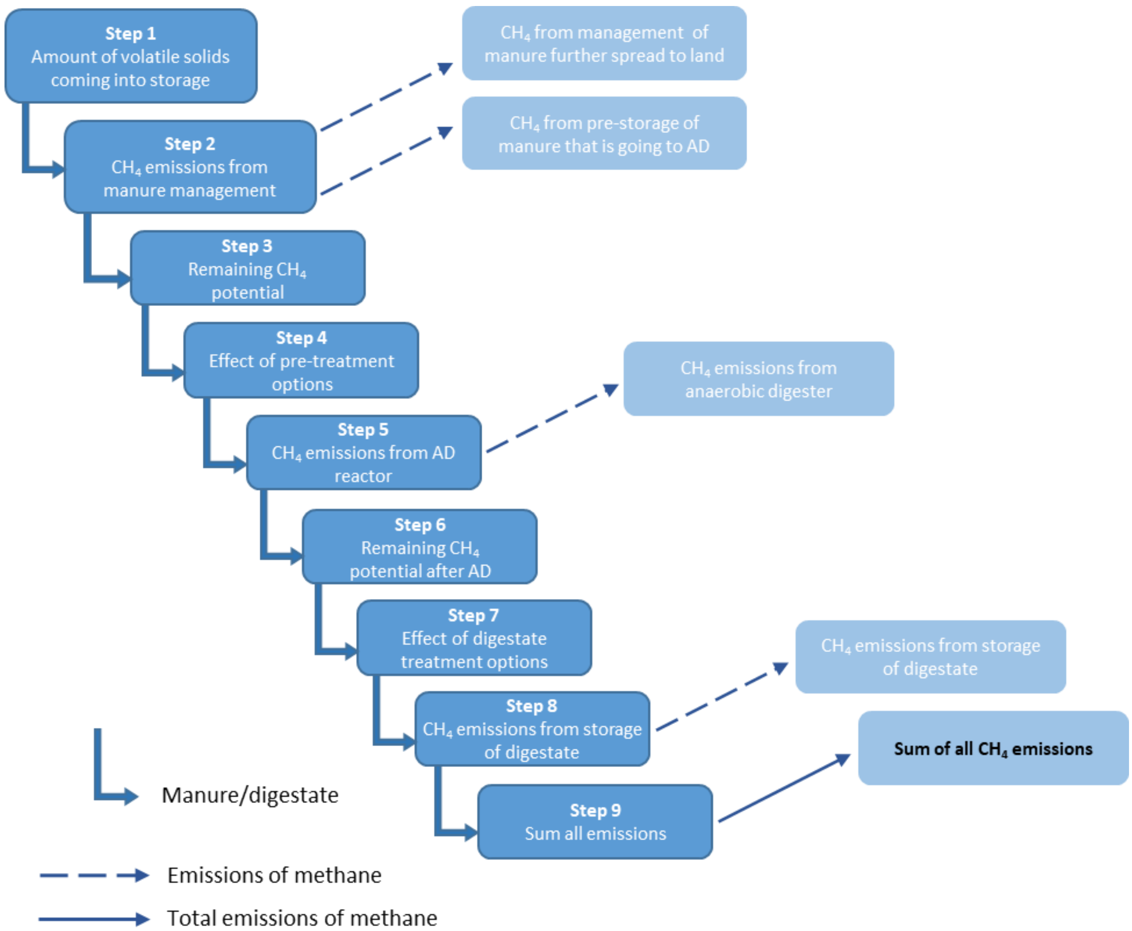


Figure 5.2: Summary of the stepwise approach of the model.

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_4 emissions from manure management systems in Norway, as well as better reflects the national manure management practices applied.

CH_4 Emissions = EF * Population

$EF_i = VS_i * 365 \text{ days/year} * Bo_i * 0.67 \text{ kg/m}^3 * \sum_{(jk)} MCF_{jk} * MS_{ijk}$

EFi = annual emission factor for defined livestock population *i*, in kg

VSi = daily VS excreted for an animal within defined population *i*, in kg

Boi = maximum CH_4 producing capacity for manure produced by an animal within defined population *i*, m^3/kg of VS

MCFjk = CH_4 conversion factors for each manure management system *j* by climate region *k*

MSijk = fraction of animal species/category *i*'s manure handled using manure system *j* in climate region *k*

The factors VS, B_0 and MCF are average factors meant to represent the whole country. The model includes a total of nine steps[32]. 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_4 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_4 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.

[32] 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 5b 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_2O 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 Aspeholen 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 5-13 and in Annex 5b. 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[33]).

The factor B_0 represents the maximum potential production of methane under optimum conditions. For dairy cows, the B_0 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.

Table 5-13: Norwegian factors for amount of manure (in dry matter - DM), VS and Bo used to estimate CH_4 from manure management with the IPCC Tier 2 method. 2022.

	Manure		VS%	VS, kg per animal	VS, total, tonnes	Bo
	kg DM/ animal	kg DM/ day				
Non-Dairy Cattle	--	--	--			
Beef cows	--	--	--	1461	160 004	0.18
Replacement heifer	--	--	--	601	64 722	0.18
Finisher heifer	--	--	--	1224	36 263	0.18
Finisher bulls	--	--	--	967	161 969	0.18
Dairy cows	--	--	--	2 001	378 293	0.23
***Poultry**:*						
Hens	13.15	--	0.9	11.83	55 239	0.38

[33] Morken (2013) Revision of the Norwegian model for estimating methane emission from manure management.

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	40 860	0.36
Ducks for breeding	30.00	--	0.9	27.9	72	0.36
Ducks for slaughter, animal places	8.12	--	0.9	7.31	510	0.36
Turkey and goose for breeding	30.00	--	0.9	27.9	408	0.36
Turkey and goose for slaughter, animal places	17.23	--	0.9	15.51	5 560	0.36
Swine:						
Piglets 4-10 weeks	38,5	--	0.9	16.57	5155	0.30
Young pigs for breeding	145,6	--	0.9	101.70	1203	0.30
Pigs for slaughter, animal places/årsdyr	140	--	0.9	118.21	45 401	
Sows	298	--	0.9	277.11	13 997	0.30
Boar	238	--	0.9	277.11	183	0.30
Sheep	--	0.32	0.9		137 757	0.19
Goats	--	0.37	0.9	123	7 460	0.18
Horses	--	4.65	0.9	1 528	137 757	0.30
Fur farming	--	0.13	0.9	45	309	0.25
Deer	--	2.42	0.9	795	6319	0.19
Reindeer	--	0.43	0.9	141	30 767	0.19

Sources: Manure, dry matter/animal, poultry : Karlengen et al. (2012), Manure dry matter/animal year: Kjos (2023), 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). B_0*: 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)[34]. A separate spreadsheet takes into account average annual temperatures in various regions of Norway, the frequency of manure removal from storage (on a monthly 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[35]. MCFs for

[34] Andrew Vander Zaag (2018) MCF Calculations and Example Spreadsheet

[35] 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

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 5-14.

Table 5-14: MCF according to animal category, manure type and manure management system. 2022.

Animal category	Manure type	MMS	2022
Mature Dairy Cattle	Slurry 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 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 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 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 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%
Horses	Slurry 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 Deep litter & solid manure	Liquid system	14.%
		Solid storage and dry lot	8.62%
	Pasture	Pasture range and paddock	NA
	Manure going to AD	Digester – total	6.82%

(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)

Poultry	Slurry 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 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 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 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, alpaca)	Slurry 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_2O

In Norway, all animal excreta that are not deposited during grazing are managed as manure. N_2O emissions from manure are estimated in a revised nitrogen model which closely follows the stepwise approach proposed in the EMEP/EEA 2023 guidelines (EEA 2023). 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_3, NO and N_2 in addition to N_2O. 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 5-15 and Annex 5b, 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 Aspeholen 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). For reindeer, N excretion factor from 2019 refinement to the 2006 IPCC Guidelines is used (IPCC 2019). 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:

1. 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)
2. 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, 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 sows, pigs for slaughter and young pigs for breeding factors from Karlengen et al (2012) were used from 1990 to 2012. In 2023 the N-factors for pigs were updated (Kjos 2023). In the years between a linear interpolation has been used. For boars and piglets factors from Kjos (2023) are used for the whole time series. 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 5b, Section 3.1. The factors are shown in Table 5-15. The factors for total N excreted are used in the estimations of N_2O emissions, whilst ammonium N is used in the estimations of NH_3 and NO_X emissions. N_2O 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 5-17 and

. This is described in section 5.3.1.2.

Table 5-15: N in excreta from different animal categories[1]. 2022. kg/animal/year unless otherwise informed in footnote.

	Total N	Ammonium N (TAN)
Dairy cattle	133.0	76.5
Beef cows	93.0	52.6
Replacement heifers2	89.3	58.7
Heifers for slaughter2	65.6	26.3
Bull for slaughter2	74.5	45.4
Sows	22.9	15.3
Boars	18.3	12.2
Piglets	2.7	1.8
Fattening pigs3	2.3	1.5
Young pigs for breeding	15	10.0
Laying hens	0.7	0.3
Chickens reared for laying3	0.05	0.02
Broilers3	0.03	0.01
Turkeys for slaughter3	0.5	0.2
Ducks and geese for slaughter3	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	5.4	2.4

Source: Karlengen et al. (2012), Aspeholen Åby et al. (2018), Volden (2022), Kjos (2023), IPCC (2019) and estimations by Statistics Norway.
[1] Includes pasture.
[2] Factors for excreted nitrogen apply for the whole lifetime of animals, and nitrogen is calculated when animals are slaughtered/replaced.
[3] 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 NH_3

Ammonia volatilized from manure storage represents, together with NO_X, the activity data in the estimations of indirect N_2O emissions from atmospheric deposition, source 3Bb5 (atmospheric deposition from manure storage). A model based on the stepwise approach proposed by the EEA (2023) is used for calculating the emissions of ammonia from manure management. The principle of the model is illustrated in Figure 5.3.

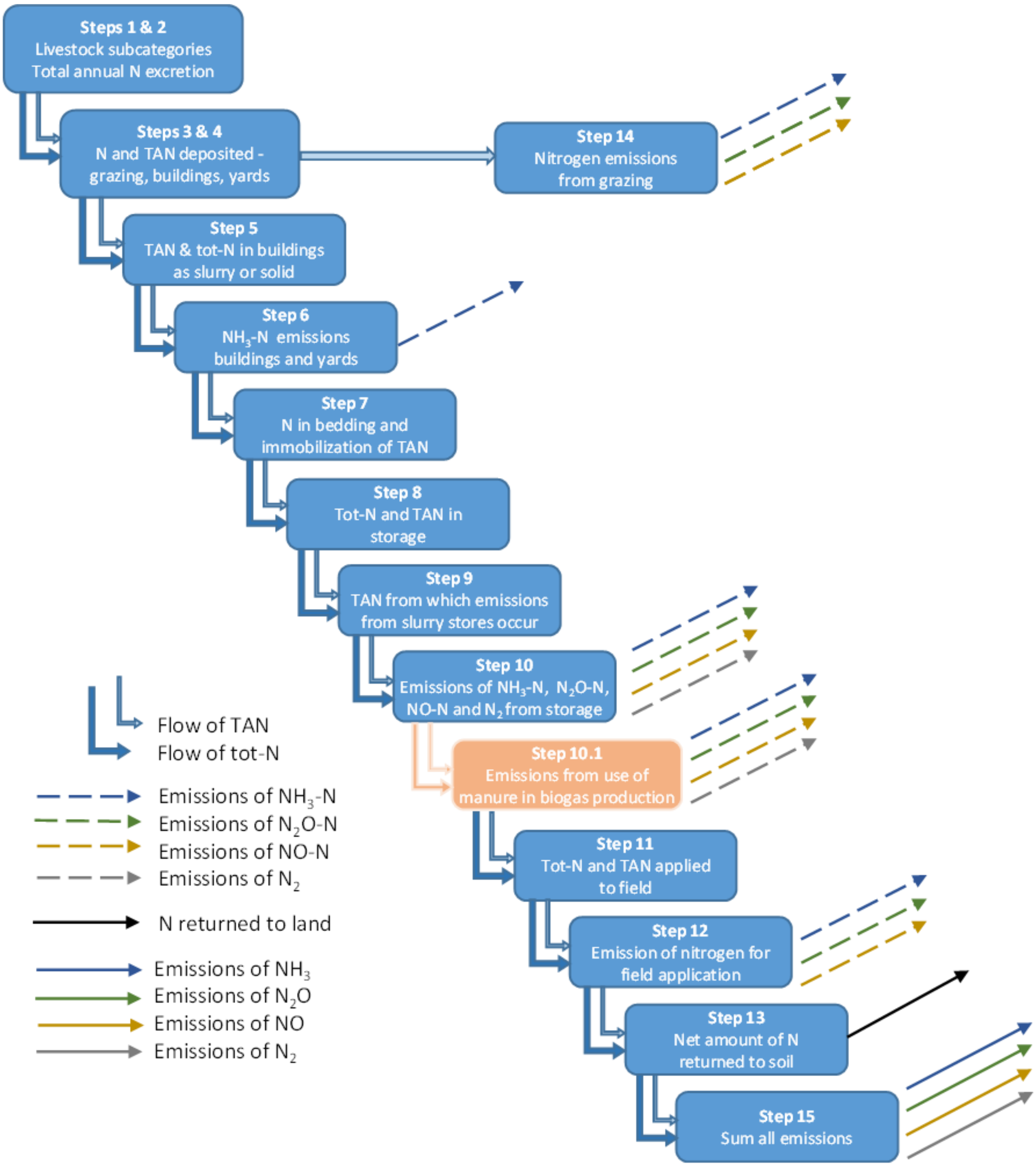


Figure 5.3: The principle of the nitrogen model

The 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 NH_3 are determined from buildings and yards and from manure storage systems. Total 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 (2023). 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 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 5-15).

5.3.1.1.4 NO_X

Nitrous oxide volatilized from manure storage represents, together with NH_3, the activity data in estimations of indirect N_2O emissions from atmospheric deposition, source 3Bb5 (atmospheric deposition from manure storage).

NO_X emissions from manure management systems are estimated according to the methodology in EEA (2023). 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 5-15 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 5-17 and

. The fractions are updated every year.

5.3.1.1.5 Indirect N_2O from manure management, 3Bb5

Deposition of nitrogen from manure management is assumed to correspond to the amount of nitrogen in the NH_3 and NO_X that volatilises from manure storage systems (including anaerobic digestion). The N_2O emissions are calculated by multiplying the amount of N from deposition with the climate adjusted IPCC default emission factor of 0.01373 kg N_2O-N/(kg NH_3-N+NO_X-N volatilized) (IPCC 2019). The factors are climate adjusted based on the distribution of 97% wet- and 3% dry climate in Norway. The climate distribution for Norway is given by National Forest Inventory data from NIBIO[36]. The emissions factors are used according to Table 11.3 in IPCC 2019 refinements to the 2006 IPCC Guidelines (IPCC 2019).

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 5-16.

[36] Christian Mohr, NIBIO, personal communication 25.09.2023.

Table 5-16: Fracleach for storage systems that are assumed to have leaching.

	$Frac_{leach}$,%
Solid storage 1	25
Cattle and swine deep bedding	15
Dry lot	25
Poultry manure	25

Source: Expert judgement by Statistics Norway and the Norwegian Agricultural Agency[37].
[1] Solid manure stored in manure cellars are not assumed to have leaching.

The IPCC default emission factor of 0.011 kg N_2O-N/kg N lost to leaching/runoff is used (IPCC 2019).

5.3.1.2 Activity data

5.3.1.2.1 CH_4, N_2O, NO_X and NH_3

Emissions are estimated from the animal population. How the animal population is estimated is described in Section 5.1.1 and Annex 5b.

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 5-17.

Norway has in 2018 developed a single model for estimating N_2O, NH_3 and NO_X 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_3 emissions compared to N_2O and NO_X emissions due to different manure storage categories being used. For the development of a single model, manure quantities used in the previous N_2O 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 Norways Census of agriculture for 2020 (Statistics Norway 2021) and presented in Table 5-18.

[37] Email from Jon Magnar Haugen, the Norwegian Agricultural Agency, 25.11.2015.

Table 5-17: Percent of total excretion per species processed by a MMS (i.e. deposited in housing) and deposited on pasture. 2022.

	% 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	27%	73%
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 5-18: Fraction of total excretion per animal category for each management system used in the estimations. 2022.

	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 animals1	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.
[1] 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_4 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[38]. 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

[38] Personal communication John Morken, NMBU, 6.8.2014

Production[39]:

- 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.

5.3.1.3 Emission factors

5.3.1.3.1 CH_4

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_2O

The IPCC default values for N_2O 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. (2019a) are implemented to the N_2O 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

[39] 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

Table 5-19. A more detailed description of the emission factors used is given in Carbon Limits (2020a).

Table 5-19: Emission factors for direct N2O emissions from manure management per manure management system, kg N2O-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. (2019a)

NH$_3$

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 5-20. All emission factors in Table 5-20 are sourced from EEA (2023), since measurements of NH$_3$ losses in animal housing and manure storage have so far not been carried out in Norway.

Table 5-20: NH$_3$ 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: EEA (2023).

As recommended in *EEA (2023)*, 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 5-21.

Table 5-21: NH_3 abatement measures for manure management systems and corresponding emission reduction, % applied to NH_3 emissions factors presented in

	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_3 emission reduction, %	30	60	80	60	40	40
NH_3 emission reduction, %	30	60	80	60	40	40

Source: Rösemann et al. (2017), UNECE (2014), Rivedal et al. (2019a).

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.

5.3.1.3.3 NO_X

The emissions factors used for NO_X emissions in manure management systems are shown in Table 5-22.

Table 5-22: NO_X and N2 emission factors for manure management per manure management system.

	kg of N in NO or N_2 (kg TAN)-1
NO_X Slurry storage	0.0001
N_2 Slurry storage	0.0030
NO_X Solid storage	0.01
N_2 Solid storage	0.30

Source: EEA (2023).

N excretions is estimated as total ammoniacal nitrogen (TAN), which is the same N excretion factor that is used in the estimations of NH_3 from manure management systems. For estimating N_2 from storage the amount is estimated as ammonia-N (TAN) and the default values for the EFs given in EEA (2023) are used.

5.3.2 Uncertainty assessment and time-series consistency

Uncertainties estimates are provided in Annex 2.

5.3.2.1 Activity data

5.3.2.1.1 CH_4

The data for the number of animals is considered to be known within ±5% and ±7% for pigs. 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_2O and NH_3

The data for the number of animals is considered to be known within ±5% and ±7% for pigs.

For the emissions from manure management, Norwegian data for N in excreta is used (Table 5-15). The nitrogen excretion factors are uncertain, but the range is considered to be within ±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 ±10%, and the division between storage and pasture, which is considered to be within ±15%.

5.3.2.2 Emission factors

5.3.2.2.1 CH_4

The emission factors, based on Tier 2 for all animal categories, are considered to have the uncertainty range ±20%.

5.3.2.2.2 N_2O

For the emission of N_2O 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_3

All emission factors for NH_3 which have been used for both housing and storage are sourced from EEA (2023). As stated in EEA (2023), uncertainties with regard to NH_3 EFs vary considerably. EEA (2023) concludes that the overall uncertainty for the United Kingdom NH_3 emissions inventory, as calculated using a Tier 3 approach, was ±21% (Webb and Misselbrook, 2004), while that for the Netherlands, also calculated using a Tier 3 approach, was ±25% (Weveret al.,2018, cited in Bruggen et al., 2018.

5.3.2.2.4 NO_X

Uncertainty has not been assessed. According to EEA (2023), uncertainty is high, ranging between -50% to + 100%.

5.3.3 Category-specific QA/QC and verification

In 2022, the VS factors for young cattle were updated as a result of the same 2021 project (Volden 2022). This resulted in 3% higher CH_4 emissions through the timeseries as an average.

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 2019, the model for calculation of CH_4 from manure was revised, taking into account the amount of manure that enters biogas facilities.

In 2018, the model for calculating emissions of N_2O, NH_3 and NO_X 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).

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_4 and N_2O 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.

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.

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).

In 2011, the Norwegian University of Life Sciences (NMBU) published a comparison of the methodologies used for calculating CH_4 emissions from manure management in Sweden, Finland, Denmark and Norway (Morken & Hoem 2011).

5.3.4 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

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_2O emissions from agricultural soils - 3D (Key categories for N_2O)

5.4.1 Category description

The emissions of N_2O from agricultural soils in Norway in 2022 amounted to 1.5 Mtonnes calculated in CO_2 equivalents. They accounted for about 33% of the total Norwegian GHG emissions from agriculture in 2022.

The emissions had minor fluctuations in the period 1990-2022. During the period 1990-2022, emissions increased by 0.4%. From 2021 to 2022, the emissions decreased by 3.7%.

Table 5-23: Emission trends for 3D Direct and indirect N2O emissions from agricultural soils (kt CO_2 equivalents).

Source category	1990	1990, % of Agriculture	2021	2022	2022, % of Agriculture	Trend 1990-2022 (%)	Trend 2021-2022 (%)
3Da1. Inorganic N fertilizers	718	14%	700	647	14%	-10%	-8%
3Da2. Organic N fertilizers	122	2.5%	143	140	3%	15%	-2%
3Da3. Urine and dung deposited by grazing animals	50	1%	48	45	1%	-11%	2-6%
3Da4. Crop residues	74	1.5%	48	53	1%	-29%	1%
3Da6. Cultivation of organic soils	337	7%	368	368	78%	9%	0%
3Db1. Indirect N2O Emissions from managed soils - Atmospheric deposition	93	2%	90	87	2%	-6%	-3%
3Db2. Indirect N2O Emissions from managed soils - Nitrogen leaching and run-off	217	4%	209	201	3%	-7%	-4%
3D. Total	1 613	32%	1 602	1 542	33%	-4%	-4%

Source: Statistics Norway and Norwegian Environment Agency

Different sources of N_2O 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_2O 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_3 and NO_X that gives indirect N_2O emissions from volatilization. NH_3 volatilized from grazing animals are also included in the estimations of indirect N_2O.

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.

IPCC Tier 1 methodologies and disaggregated default emission factors (IPCC 2019) are used for estimating direct and indirect N_2O emissions from managed soils. The factors are climate adjusted based on the distribution of 97% wet- and 3% dry climate in Norway. The climate distribution for Norway is given by National Forest Inventory data from NIBIO[40]. The emissions factors are used according to Table 11.1 and 11.3 in IPCC 2019 refinements to the 2006 IPCC Guidelines (IPCC 2019).

Emissions of N_2O from agricultural soils are key categories according to the Approach 2 key category analysis.

5.4.1.1 Inorganic N fertilizers, 3Da1

5.4.1.1.1 Methodological issues

N_2O

The direct emissions of N_2O 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 climate adjusted IPCC default emission factor (IPCC 2019).

NH_3

The calculations of NH_3 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_3 during spreading.

NO_X

The nitrogen in synthetic fertilizer applied to soil has been multiplied with the default tier 1 emission factor to estimate the nitric oxide (NO_2) emission from crop production.

[40] Christian Mohr, NIBIO, personal communication 25.09.2023.

5.4.1.1.2 Activity data

N_2O

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_3

For the calculation of the emission of NH_3, the amount of total N in the fertilizer is used (the same as for estimating N_2O). For the calculation of the emission of NH_3, we need a specification of the use of different types of synthetic fertilizer since the NH_3 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.

The emissions of NH_3 from inorganic fertilizer was calculated taking into account the incorporation into soil when spreading. The practice here for Norwegian potato, vegetable and grain productions was evaluated in a report performed by Norwegian Institute of Bioeconomy Research (NIBIO) (Rivedal et al. (2019a) and Rivedal et al. (2019b)).

NO_X

For the calculation of the emission of NO_X, the amount of total N in the fertilizer is used (the same as for estimating N_2O).

5.4.1.1.3 Emission factors

N_2O

The climate adjusted IPCC default emission factor of 0.0157 kg N_2O-N/kg N applied from IPCC 2019 refinements has been used (IPCC 2019).

NH_3

Different types of synthetic fertilizers are being used, resulting in different emissions of NH_3. Their respective share is based on sales statistics provided annually by the Norwegian Food Safety Authority for the years from 2000. For earlier years the distribution is based on data from 1994. The NH_3 emission factors for the different types of fertilizers are shown in Table 5-24.

Table 5-24: Emission factors for NH_3 for different fertilizers. kg NH_3 per kg N.

Fertiliser	Emission factor (kg NH_3 per kg N)
Urea	0.155
Ammonium sulphate	0.09
Ammonium nitrate	0.015
Liquid ammonia	0.019
Calcium and boron calcium nitrate	0.05
Calcium ammonium nitrate and other nitrate types	0.08
NPK (Nitrogen, phosphorus, potassium)	0.05
Magnesium fertiliser	0.05
Diammonphosphate	0.05
Other NP fertiliser	0.05
NK fertiliser	0.015

Source: EEA (2019)

More information about the calculation of $frac_{gasf}$ and the NH_3 emission factors for the different types of fertilizers is provided in Annex 5b, section 4.

NO_X

The tier 1 default emission factor of 0.04 kg NO_2/ kg fertilizer-N applied (EEA 2023) has been used.

5.4.1.2 Animal manure applied to soils, 3Da2

5.4.1.2.1 Methodological issues

N_2O

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_2O themselves. NH_3 emissions in housing and storage, and N_2O 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 direct N_2O emissions from animal manure applied to managed soils is calculated by multiplying the total amount of N in manure used as fertilizer with the climate adjusted emission factor based on the IPCC default emission factors for wet and dry climate (IPCC 2019). This amount is equivalent to total N excreted from the animals deducted for the amount dropped during grazing.

NH_3

NH_3 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_3 during spreading takes into account the amount of nitrogen in the NH_3, NO_X, and N_2 that volatilises during housing and storage, as well as the N lost as N_2O 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_X

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_2O, NH_3 and NO_X

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_2O, NH_3 and NO_X 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_3 emissions estimates, while the N_2O 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 0 and Annex 5b.

Nitrogen factors are estimated by Karlengen et al (2012),, Aspeholen Åby et al. (2018) and Volden (2022). In the estimations of NH_3 losses, the factors of N excretion correspond to the estimated nitrogen excreted in the urine.

Table 5-25: Sources for activity data for emissions from animal manure applied to soils.

	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 5b, section 3.	Karlengen et al. (2012), Aspeholen 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.

Table 5-26: Parameters included in the estimation of NH_3 emissions from manure.

	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$_2$O

The emission factor used is based on the disaggregated IPCC default factors for dry and wet climate (IPCC 2019). The factor 0.00597 kg N_2O-N/kg N applied has been used.

NH$_3$

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 5-27.

Table 5-27: Emissions factors for NH_3-N for various methods of spreading of manure. % of ammonium N.

Meadow			Spring	Summer	Autumn
Spreading method	**Added water**		**kg NH_3-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_3-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 5-27 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 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.

NO_X

The tier 1 default emission factor of 0.04 kg NO_2/kg fertilizer-N applied (EEA 2023) has been used.

5.4.1.3 Sewage sludge applied to soils, 3Da2

5.4.1.3.1 Methodological issues

N_2O

The emission factor is based on the disaggregated IPCC default factors for dry and wet climate. The factor 0.00597 kg N_2O-N/kg N applied (IPCC 2019) is used from submission 2024 and is a result of 97% wet and 3% dry climate.

Data for the N_2O emission arising from sewage sludge applied on fields has been calculated by multiplying the amount of nitrate in the sewage sludge applied with the climate adjusted IPCC default emission factor.

NH_3

The NH_3 emissions from sewage sludge used as fertilizer is estimated by multiplying the total N in sewage sludge with the EEA Guidebook 2023 default emission factor for sewage sludge.

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

N_2O, NH_3 and 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_2O

The emission factor is based on disaggregated IPCC default factors for dry and wet climate. The factor 0.00597 kg N_2O-N/kg N applied (IPCC 2019) has been used.

NH_3

The EEA Guidebook 2023 default emission factor for sewage sludge of 0.13 kg NH_3/kg N applied has been used (EEA 2023).

NO_X

The tier 1 default emission factor of 0.04 kg NO_2/kg fertilizer-N applied (EEA 2023) has been used.

5.4.1.4 Other organic fertilizers applied to soils, 3Da2

5.4.1.4.1 Methodological issues

N_2O

Emissions of N_2O 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_3

The estimated amounts of N in organic fertilizers are multiplied with the EEA Guidebook 2023 default emission factor for other organic fertilizer applied.

NO_X

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_2O, NH_3 and NO_X

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 2022 were estimated to less than 0.01 ktonnes N_2O.

5.4.1.4.3 Emission factors

N_2O

The emission factor is based on disaggregated IPCC default factors for dry and wet climate. The factor 0.00597 kg N_2O-N/kg N applied (IPCC 2019).

NH_3

The EEA Guidebook 2023 default emission factor for other organic fertilizer of 0.08 kg NH_3/kg N applied has been used (EEA 2023).

NO_X

The tier 1 default emission factor of 0.04 kg NO_2/kg fertilizer-N applied (EEA 2023) has been used.

5.4.1.5 Urine and dung deposited by grazing animals, 3Da3

5.4.1.5.1 Methodological issues

N_2O

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 5-18). The amount of N deposited during grazing is multiplied with emission factors based on the climate disaggregated IPCC default emission factor. The factors are climate adjusted and amounts to 0.00588 N_2O-N/kg N for cattle, swine and poultry and 0.003 N_2O-N/kg N for goat, deer and reindeer (IPCC 2019).

NH_3

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_2O and NH_3

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 5b.

5.4.1.5.3 Emission factors

N_2O

The emissions of N_2O from animals on pastures are calculated using the disaggregated IPCC default emission factors(IPCC 2019). The factors are climate adjusted and amounts to 0.00588 N_2O-N/kg N for cattle, swine and poultry and 0.003 N_2O-N/kg N for sheep, horse, goat, deer and reindeer.

NH_3

The emission factors used for the calculation of the NH_3 emissions from grazing animals are shown in Table 5-28. These are the same as the emission factors recommended in EEA (2023).

Table 5-28: Ammonia emission factors from droppings from grazing animals on pasture.

	NH_3 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 (2023). For deer and reindeer EF for dairy cattle is used

5.4.1.6 N_2O from crop residues, 3Da4

5.4.1.6.1 Methodological issues

N_2O emissions associated with crop residue decomposition are estimated using the IPCC tier 1 approach (IPCC 2019) 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) and Carbon Limits (2023). 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 2019) are assumed to be sufficiently representative.

The methodology for N_2O emissions from crop residues was updated for the 2024 submission, where it is now based on the updated equation detailed in the IPCC's 2019 refinement to the 2006 guidelines (described below) (IPCC 2019). Input data remains the same as in previous submissions.

The factors are 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 $Frac_{Renew}$ 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_{AG} and N_{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 ($FRAC_{Remove}$) has been estimated to 0.15 of the total straw production from 1990 to 2000, and 0.13 from 2001 to 2022 according to expert opinion.

For wheat and ryethe ratio of above-ground residues (straw) to harvested grain yield (R_{AG}) has been estimated to 0.95 and 1.1respectively, and the N fraction in the straw (N_{AG}) for wheat, barley, and oats has been estimated to 0.0042, 0.005 and 0.033 respectively (Grønlund et al. 2014). R_{AG} and N_{AG} values for all other crop types are taken from IPCC (2019).

The fraction of crop residue burned on field was updated in 2012 by the Norwegian Agricultural Authorities[41]. This reduced the fraction for 2011 from 7.5 to 4%.

[41] Johan Kollerud, Norwegian Agricultural Agency, unpublished material 2012.

The updated formula used for N-content in crop residues as used in the 2024 submission is as follows:

$$F_{CR} = \sum_{T} \left[\left[AGR_{(T)} * N_{AG(T)} * \left(1 - Frac_{Remove(T)} - \left(Frac_{Burnt(T)} \ * C_f\right)\right) \right] + \left[BGR_{(T)} * N_{BG(T)} \right] \right]$$

Where:
F_{CR} = N in crop residue returned to soils (tonnes)
$AGR_{(T)}$ = Annual total amount of above-ground crop residue for crop T
$N_{AG(T)}$ = N content of above-ground residues for crop T, kg N (kg d.m.)
$Frac_{REMOVE(T)}$ = Fraction of crop residue removed for purposes as feed beddings and energy for crop T
$Frac_{BURN(T)}$ = Fraction of crop residue burned on field for crop T
C_f = Combustion factor
$BGR_{(t)}$ = Annual total amount of belowground crop residue for crop T
$N_{BG(T)}$ = N content of belowground crop residues for crop T

Noteworthy changes from updating to the newer formula include:

- The revised method to estimate above-ground N content gives slightly lower values for some crops
- The implementation of the combustion factor C_f, eliminating a source of underestimation in the N content of crop residues
- The use of area burnt only on above-ground residues in the new formula, as opposed to both above- and below-ground residues in the old model, eliminating another source of underestimation of N content.

Changes to emissions estimates as result of implanting the new formula are discussed in further detail in chapter 10.

Table 5-29: Factors used for the calculation of the nitrogen content in crop residues returned to soils.

	Share of meadows	$Frac_{DM}$	$Frac_{RENEW}$	R_{AG}	N_{AG}	$Frac_{REMOVE}$	R_{BG}	N_{BG}	C_f
Perennial grasses	0.45	0.9	0.1	0.3	0.015	0	1.04	0.011	0
Grass-clover mixtures	0.55	0.9	0.1	0.3	0.019	0	1.04	0.013	0
Wheat	--	0.85	1	0.95	0.0042	0.13	0.47	0.009	0.9
Rye	--	0.85	1	1.1	0.005	0.13	0.46	0.011	0.85

Rye wheat	--	0.85	1	1.09	0.006	0.13		0.009	0.9
Barley	--	0.85	1	0.76	0.005	0.13	0.39	0.014	0.85
Oats	--	0.85	1	0.92	0.0033	0.13	0.48	0.008	0.85
Rapeseed	--	0.85	1	1.1	0.006	0.15	0.46	0.009	0.85
Potatoes	--	0.22	1	0.1	0.019	0	0.22	0.014	0
Roots for feed	--	0.22	1	0.1	0.019	0		0.014	0
Green fodder (non-N fix)	--	0.9	1	0.3	0.015	0	0.70	0.012	0
Vegetables	--	0.22	1	0.1	0.019	0	0.22	0.014	0
Peas	--	0.91	1	1.1	0.008	0	0.40	0.008	0
Beans	--	0.91	1	1.1	0.008	0	0.40	0.008	0

Source: Grønlund et al. (2014), Carbon Limits (2023)

5.4.1.6.2 Activity data

As activity data for the estimations of emissions of N_2O from crop residues are annual crop yield statistics from Statistics Norway used.

5.4.1.6.3 Emission factors

The climate adjusted emission factor of 0.00597 kg N_2O-N/kg N applied has been used. This factor is based on the disaggregated IPCC default emission factors (IPCC 2019).

5.4.1.7 N_2O 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_2O emissions are reported from this sub-category. For more information, see NIR Chapter 6.13 Direct N_2O from N mineralization and immobilization – 4(III).

5.4.1.8 N_2O from cultivation of organic soils, 3Da6

5.4.1.8.1 Methodological issues

Large N_2O 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_2O-N/ha per year for cropland and 1.6 kg N_2O-N/ha per year for grassland (IPCC 2014).

5.4.1.9 Indirect N_2O 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_2O formation. Deposition of nitrogen are assumed to correspond to the amounts of NH_3 and NO_X that volatilises during the spreading of synthetic fertilizers, manure, sewage sludge and other organic fertilizers, and NH_3 volatilisation from pastures. The N_2O emissions are calculated by multiplying the amount of N from deposition with the factor based on IPCC default emission factor (IPCC 2019).

5.4.1.9.2 Activity data

Information about the estimation of NH_3 and NO_X from spreading of synthetic and organic fertilizers and the estimation of NH_3 volatilisation from pastures are given in section 5.4.1.1- 5.4.1.5.

5.4.1.9.3 Emission factors

$\underline{N_2O}$

The climate adjusted IPCC default emission factor of 0.01373 kg N_2O-N/(kg NH_3-N+NO_X-N volatilized) (IPCC 2019) is used to calculate indirect emissions of N_2O from volatilized NH_3 and NO_X.

5.4.1.10 Indirect N_2O 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_2O 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 $Frac_{leach}$ estimated in this study was 22% of the N applied. This value is a median of $Frac_{leach}$ 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_2O (IPCC 2019).

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

<u>N_2O</u>

The IPCC default emission factor of 0.011 kg N_2O-N/kg N lost to leaching/runoff is used (IPCC 2019).

5.4.2 Uncertainty assessment 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 ±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 ±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 NH_3 *emissions:* The data is based on national figures for NH_3 emission from agriculture. These are within ±30% (Rypdal & Zhang 2000)
Leakage of nitrogen: The upper limit for the leakage is the applied nitrogen. The uncertainty is roughly about ±70% (Rypdal & Zhang 2000).

5.4.2.2 Emission factors

N_2O

Uncertainty estimates used for the N_2O emission factors are given in Annex 2.

NH_3

The uncertainty in the estimate of NH_3 emissions from use of fertilizer is assessed to be about ±20% (Rypdal & Zhang 2001). This uncertainty could be lower if better data on fertilizer composition were obtained. The uncertainty is higher for animal manure, ±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 uncertainness 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 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.

In 2018, the model for calculating emissions of N_2O, NH_3 and NO_X 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.

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 & Heldal 2015) and 2015-2018 (Kolle & Oguz-

Alper 2020). Data from the manure survey of 2013 was implemented in the estimations of N_2O and CH_4 emissions from manure in the 2015 submission, and in the 2016 submission for NH_3.

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.

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.

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.

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).

5.4.4 Category-specific recalculations

There are recalculations performed for this source category this year, see chapter 10 for details.

5.4.5 Category-specific planned improvements

In the 2025 submission, new NH_3 emission factors from EEA (2023) for inorganic N-fertilizers are planned to be implemented.

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 2022, and the emissions have decreased by 89% 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.

5.5.2 Methodological issues

CH_4, N_2O

Emissions from the burning of crop residues are calculated in accordance with a Tier 1 approach (EEA 2023):

$E_{Pollutant} = AR_{residue\_burnt} * EF_{Pollutant}$

Where:

$E_{Pollutant}$ = emission (E) of pollutant

$AR_{residue\_burnt}$ = activity rate (AR), mass of residue burnt (dry matter)

$EF_{Pollutant}$ = emission factor (EF) for pollutant

5.5.3 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 ($Frac_{BURN}$) 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_2O from crop residues.

Table 5-30: Emission factors for agricultural residue burning.

Components	Emission factors	Unit	Source
CH_4	2.7	kg/ tonnes crop residue (d.m.) burned	(IPCC 2006)
N_2O	0.07	kg/ tonnes crop residue (d.m.) burned	(IPCC 2006)

5.5.4 Uncertainty assessment and time-series consistency

Uncertainty estimates are given in Annex 2.

5.5.5 Category-specific QA/QC and verification

In 2002, the emissions of CH_4 and N_2O, 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.

5.5.6 Category-specific recalculations

There have been no recalculations performed for this source category this year.

5.5.7 Category-specific planned improvements

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

5.6 Emissions from liming – 3G

5.6.1 Category description

Liming of agricultural soils and lakes gives emissions of CO_2. The source contributed with about 2.6% of the agricultural greenhouse gas emissions in year 2022, and emissions have decreased by 47% since 1990.

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.

5.6.2 Methodological issues

A Tier 1 method was used with specific emission factors for limestone and dolomite.

5.6.3 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.

5.6.4 Emission factors

The default emission factor values provided by IPCC are 0.12 Mg CO_2 C Mg^{-1} for limestone and 0.13 Mg CO_2 C Mg^{-1} for dolomite. For limestone this is equal to emissions of 0.44 Mg CO_2 per Mg $CaCO_3$ 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 Mg CO_2 C Mg^{-1}), as only the total amount of lime was available.

5.6.5 Uncertainty assessment and time-series consistency

The amount of limestone and dolomite used is expected to be known with an uncertainty on ±5 percent and the emission factor with an uncertainty of ±10%.

5.6.6 Category-specific recalculations

There have been no recalculations performed for this source category this year.

5.6.7 Category-specific planned improvements

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

5.7 Emissions from urea application – 3H

5.7.1 Category description

Urea application on agriculture soils is a minor source of CO_2 emissions in the inventory and contributes with about 0.002% of the agriculture greenhouse gas emissions in 2022.

5.7.1.1 Methodological issues

Application of urea results in an emission of CO_2. Norway uses a Tier 1 methodology. Annual CO_2 emissions from urea fertilisation are estimated according to equation 11.13 (IPCC 2006):

CO_2–C Emission = M • EF,

where:

CO_2–C Emission = annual C emissions from urea application, tonnes C yr^{-1}

M = annual amount of urea fertilisation, tonnes urea yr^{-1}

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 NH_3 from use of synthetic fertilizers. The amount used is very small, and consequently this is a very small source of CO_2 emissions.

5.7.1.3 Emission factors

The default emission factor of 0.20 is used (IPCC 2006).

5.7.2 Uncertainty assessment and time-series consistency

5.7.2.1 Activity data

The uncertainty that applies to use of mineral fertilizers on ±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_2 from the atmosphere. This is a conservative approach (IPCC 2006). No uncertainty estimate is found, and Norway uses an uncertainty of ±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),* selected parts of the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014) (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/emission factors 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 (details in chapter 1.4), have been conducted by the Norwegian Institute of Bioeconomy Research (NIBIO).

6.1 Sector Overview

6.1.1 Emissions and removals in 2022

The LULUCF sector includes both emissions of greenhouse gasses (GHG) CO_2, N_2O and CH_4 to the atmosphere and removal of atmospheric CO_2. The balance of the two is net emissions or removals in the LULUCF sector. Positive numbers are used to report net emissions of GHGs, while negative numbers are used to report removals of CO_2.

In the current reporting year, the LULUCF sector achieved a net removal of -13 746 kt CO_2 equivalents. This constitutes approximately 28% of the total emissions from all other sectors than LULUCF in the Norwegian GHG accounting.

The main contributor to the CO_2 removals in the LULUCF sector was forest land, with net removals of -17 859 kt CO_2 equivalents. The harvested wood products (HWP) pool also contributed to removals, with net removals of -514 kt CO_2 equivalents. Lastly, grasslands recorded a net removal of -79 kt CO_2 equivalents.

On the other hand, there were net emissions from cropland, settlements, and wetlands. The highest emissions were from cropland, primarily drained organic soils, with a total of

2 512 kt CO_2 equivalents. This was followed by emissions from settlements amounting to 1 819 kt CO_2 equivalents. Wetlands reported the least emissions with 368 kt CO_2 equivalents. Consequently, among the six land-use categories in the LULUCF sector, croplands and settlements were the land-use categories contributing to the largest net emissions. In Norway, the category "other lands" refers to wasteland areas with bare soil, rocks, and ice with no significant C pools, and therefore do not record any emissions.

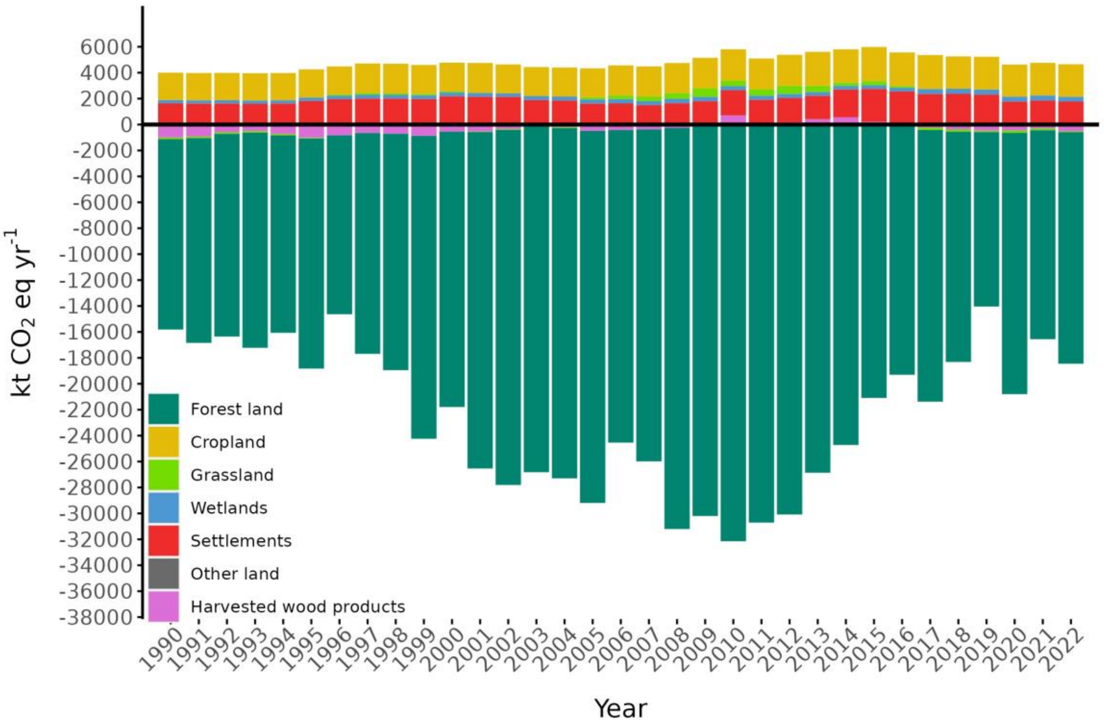


Figure 6.1: Net CO_2 emissions and removals (kt CO_2 equivalents per year) from the LULUCF sector by land-use category (forest land, cropland, grassland, wetlands, settlements, other land, and harvested wood products) from 1990 to 2022, including emissions of N_2O and CH_4. Negative values are net removals, and positive values are net emissions. Source: Norwegian Institute of Bioeconomy Research.

Within the category of forest land remaining forest land, the major contributors to removals were living biomass, litter, and dead wood. Living biomass accounted for the largest share, contributing with -10 570 kt CO_2 of the total removals. This was followed by litter and dead wood, which contributed -6 194 kt CO_2 and -1 252 kt CO_2 to the total CO_2 removals, respectively. Land converted to forest land further added to the removals, contributing a total of -1 122 kt CO_2. This was primarily due to components like litter (-573 kt CO_2), dead wood (-395 kt CO_2), living biomass (-154 kt CO_2). However, not all activity on forest land resulted in CO_2 removals. Net emissions were recorded from forest land remaining forest land, primarily from drained organic soils, which amounted to 1 213 kt CO_2. In contrast, the mineral soil on the same land category constituted a removal of -144 kt CO_2. Drained organic soil from lands converted to forest land was another source of emissions, although at a smaller scale, totalling 17 kt CO_2. See Figure 6.2 below.

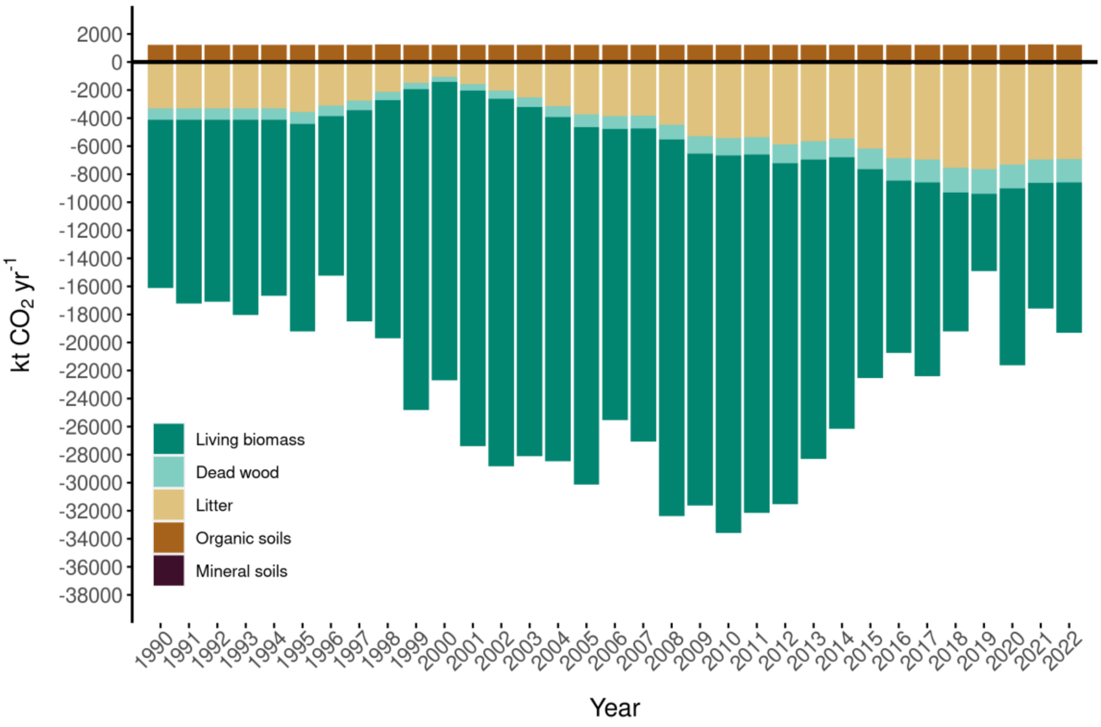


Figure 6.2: Emissions and removals of CO_2 on forest land, including both remaining and land converted to forest land. The graph shows the aggregated emissions and removals for both categories. Carbon pools can either act as a source or sink of $C0_2$ depending on the category, although this might not always be visible in the graph. Source: Norwegian Institute of Bioeconomy Research.

The category of cropland remaining cropland significantly impacted the emissions of LULUCF sector. The major source of CO_2 emissions came from organic soils, with a considerable amount of 1 813 kt CO_2. When it comes to land converted to cropland, it's clear that the DOM pool was the largest contributor to the emissions with 325 kt CO_2. Organic soils also added to the emissions, contributing 127 kt CO_2. The emissions from the living biomass pool, on the other hand, were smaller (122 kt CO_2) and are therefore not as impactful in this context. See Figure 6.3 below.

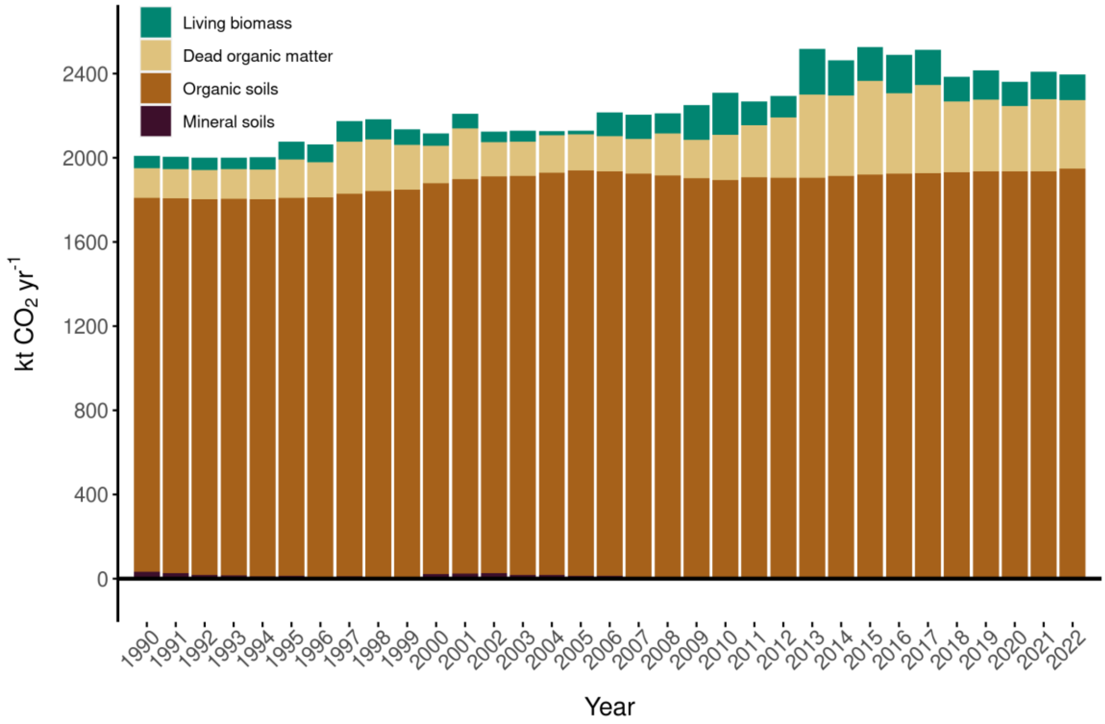


Figure 6.3: Emissions and removals of CO_2 on cropland, including both remaining and land converted to cropland. The graph shows the aggregated emissions and removals for both categories. Carbon pools can either act as a source or sink of $C0_2$ depending on the category, although this might not always be visible in the graph. Source: Norwegian Institute of Bioeconomy Research.

A large portion of the emissions in grasslands came from the category land converted to grassland, in which the DOM pool was the main source, releasing 366 kt of CO_2. In contrast, grassland remaining grassland was primarily a site of CO_2 removal. The living biomass pool was the key contributor, removing as much as -580 kt of CO_2. See Figure 6.4 below.

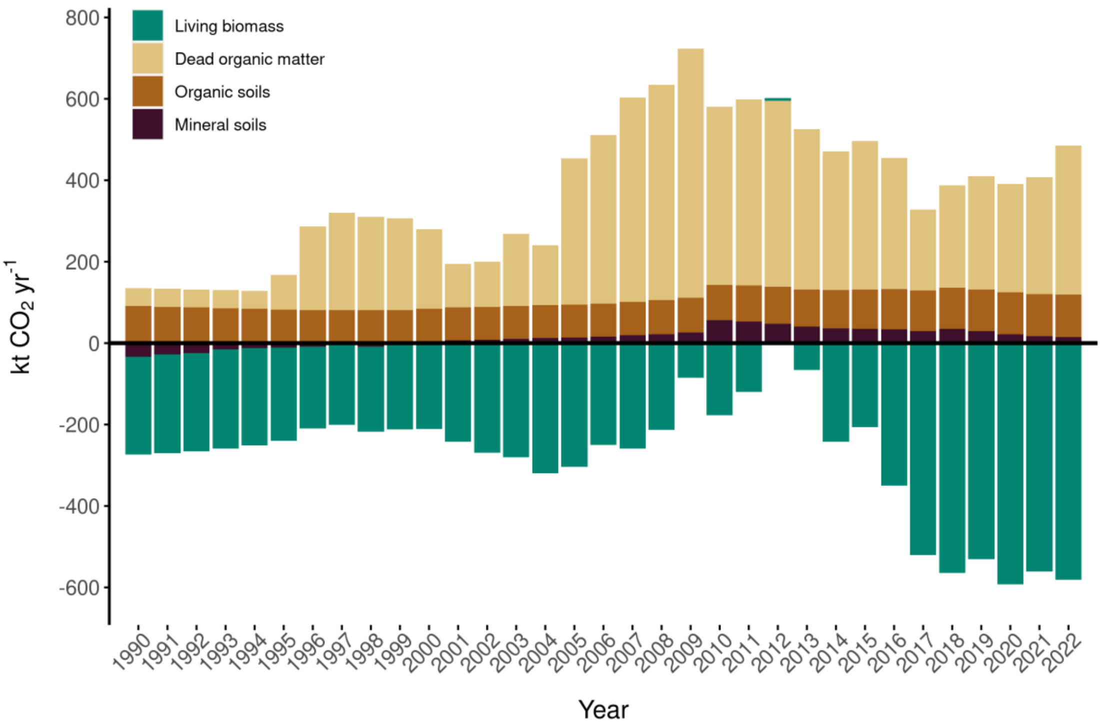


Figure 6.4: Emissions and removals of CO_2 on grassland, including both remaining and land converted to grassland. The graph shows the aggregated emissions and removals for both categories. Carbon pools can either act as a source or sink of $C0_2$ depending on the category, although this might not always be visible in the graph. Source: Norwegian Institute of Bioeconomy Research.

The category of wetlands remaining wetlands consists of wooded mires in managed and unmanaged wetlands, peat extraction (only existing areas), and mires with ditches in organic soil. The organic soils (mires with ditches and peat extraction) were the main emission source, accounting for 246 kt and 82 kt of CO_2 respectively. The living biomass pool, on the other hand, acted as a small sink, removing a total of -67 kt CO_2. For land converted to wetlands, the emissions were smaller. See Figure 6.5 below.

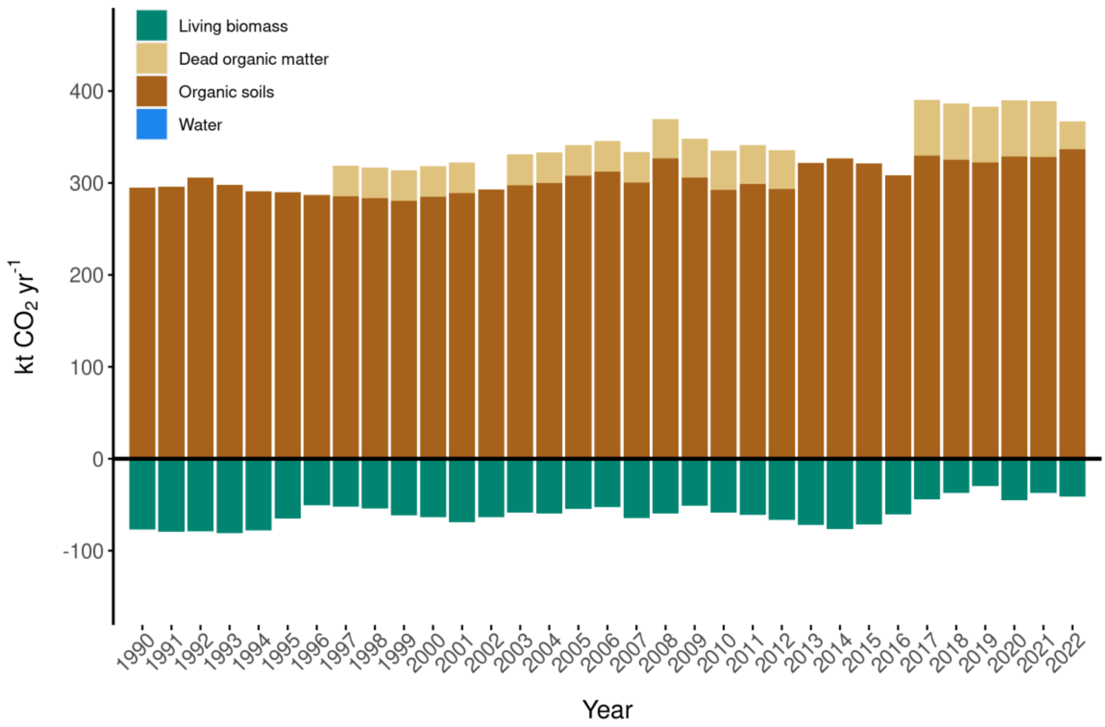


Figure 6.5: Emissions and removals of CO_2 on wetland, including both remaining and land converted to wetland. The graph shows the aggregated emissions and removals for both categories. Carbon pools can either act as a source or sink of $C0_2$ depending on the category, although this might not always be visible in the graph. Source: Norwegian Institute of Bioeconomy Research.

Lands converted to settlements resulted in emission of CO_2. The largest emission came from the DOM pool, releasing a substantial 877 kt of CO_2. This was followed by the living biomass pool, emitting 471 kt of CO_2. Meanwhile, settlements remaining settlements also added to the emissions, although on a smaller scale. The organic soils in these areas released 173 kt of CO_2. See Figure 6.6 below.

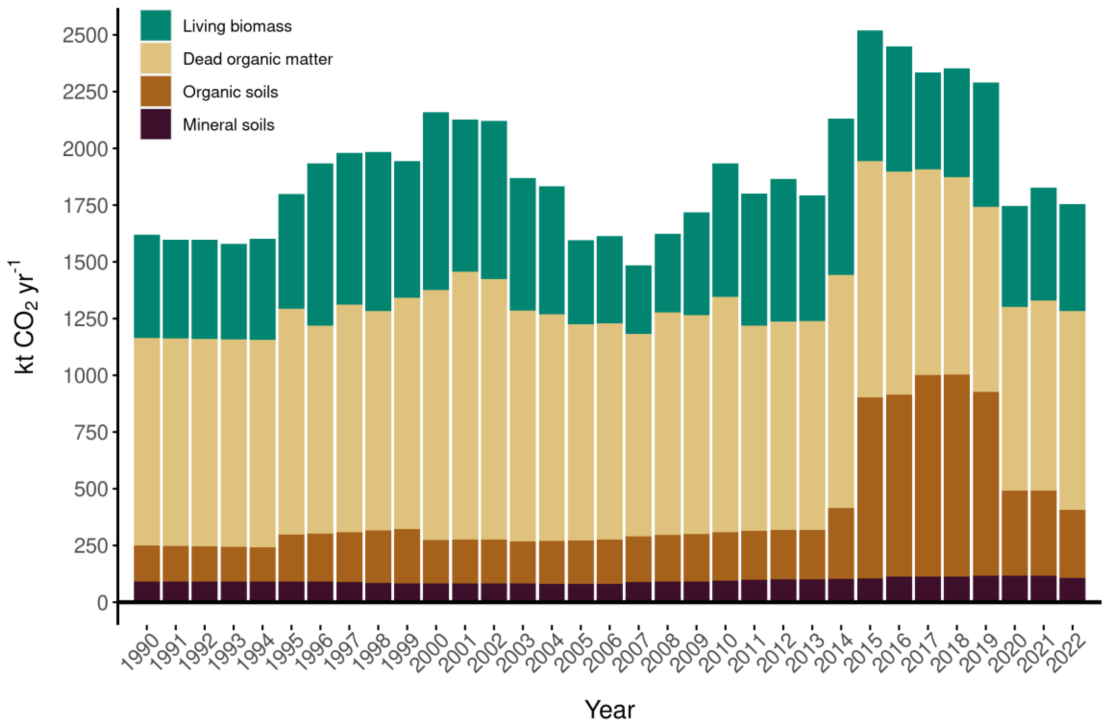


Figure 6.6: Emissions and removals of CO_2 on settlements, including both remaining and land converted to settlements. The graph shows the aggregated emissions and removals for both categories. Carbon pools can either act as a source or sink of $C0_2$ depending on the category, although this might not always be visible in the graph. Source: Norwegian Institute of Bioeconomy Research.

The Other land sector did not contribute to either CO_2 emissions or removals within the LULUCF sector. For both categories - other land remaining other land, and land converted to other land - there were no emissions or removals reported.

Figure 6.7 illustrates the net CO_2 emissions and removals of all land uses arranged in descending order of their respective impact on the LULUCF sector. Taken together, the importance of forest land compared to the other land uses is evident. In particular, the living biomass and dead organic matter (litter and dead wood) pools contribute significantly to the removals, and consequently to the results of the LULUCF sector.

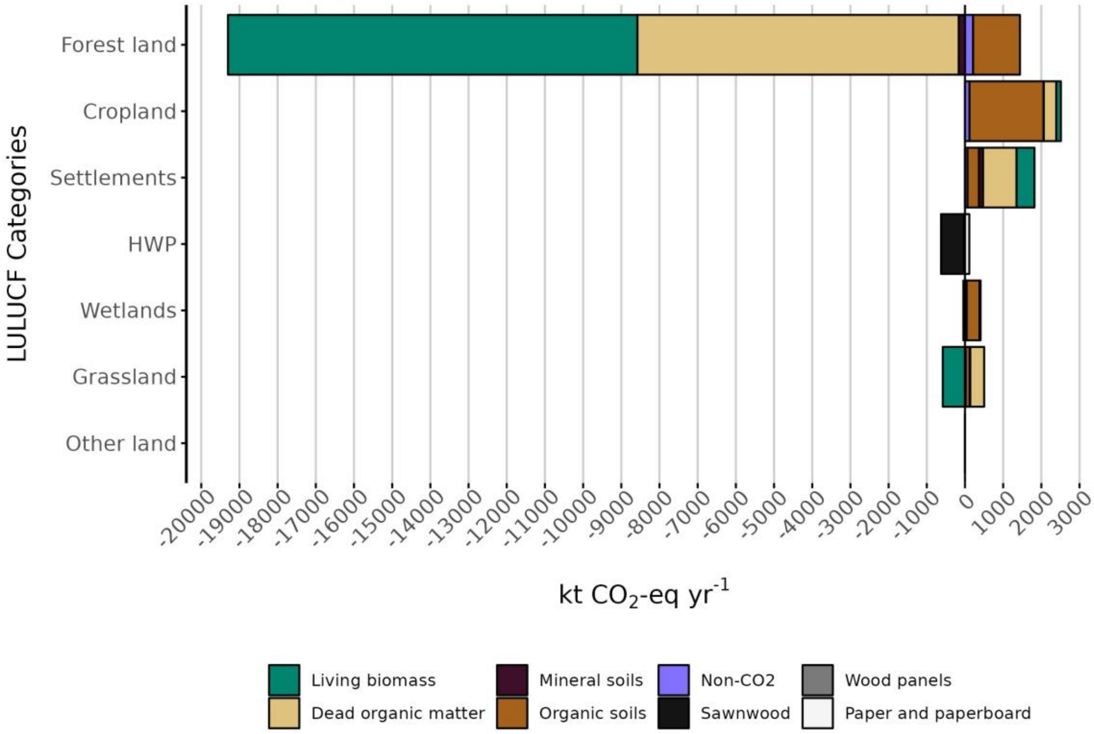


Figure 6.7: Net CO_2 emissions and removals (kt CO_2 equivalents per year) by land-use category (forest land, cropland, grassland, wetlands, settlements, other land, and harvested wood products) for 2022, including emissions of N_2O and CH_4. Negative values are net removals, and positive values are net emissions. Land-use categories are ordered from highest to lowest impact on the LULUCF sector. Source: Norwegian Institute of Bioeconomy Research.

6.1.2 Trends

Over the years, the LULUCF sector has seen noticeable changes. The average annual net removals from 1990 until the current reporting year was about -17 662 kt CO_2 equivalents per year.

Table 6-1: Change in net emissions and removals from 1990 to latest reporting year. Sources/sink presented for each trend category accounts for 90% of the observed change within the category.

Trend category	Land Use Change Category	Source/Sink	1990 (kt CO_2 eq)	2022 (kt CO_2 eq)	Change (kt CO_2 eq)	Percentage of total change
Reduced removals	Forest land remaining forest land	Living biomass	-11999	-10570	1429	87.9
Increased emission	Export	Paper and paperboard	-294	40	335	16.9
	Forest land converted to grassland	DOM	44	366	322	16.3
	Cropland remaining cropland	Organic soil	1534	1813	278	14.1
	Domestic	Wood panels	-155	71	226	11.4
	Forest land converted to cropland	DOM	140	325	185	9.3
	Settlements remaining settlements	Organic soil	27	173	146	7.4
	Forest land converted to cropland	Living biomass	59	120	61	3.1
	Grassland remaining grassland	Mineral soil	-28	25	53	2.7
	Domestic	Paper and paperboard	27	73	45	2.3
	Other wetlands remaining other wetlands	Organic soil	201	246	45	2.3
	Forest land converted to other wetlands	DOM	0	30	30	1.5
	Wetlands converted to grassland	Organic soil	0	30	30	1.5
	Forest land converted to other wetlands	Living biomass	0	24	24	1.2
Increased removals	Forest land remaining forest land	Litter	-2850	-6194	-3344	63.1
	Forest land remaining forest land	Dead wood	-576	-1252	-676	12.8
	Grassland remaining grassland	Living biomass	-261	-580	-318	6.0

	Domestic	Sawnwood	-111	-326	-215	4.1
	Grassland converted to forest land	Dead wood	-123	-246	-124	2.3
Reduced emission	Wetlands converted to cropland	Organic soil	124	27	-98	36.2
	Forest land converted to settlements	DOM	915	877	-38	14.2
	Forest land converted to settlements	Organic soil	126	95	-31	11.5
	Forest land converted to cropland	Organic soil	104	78	-25	9.3
	Forest land converted to settlements	Mineral soil	120	96	-24	8.9
	Grassland remaining grassland	Organic soil	91	71	-20	7.5

For forest land remaining as forest land, the average carbon removals by living biomass have decreased from 1990 to 2022. The average carbon removals by dead organic matter and mineral soil have increased during the same period.

Exported Paper and paperboard under HWP has had the largest in average increase in emissions, going from a net sink to net emission source. This trend has been seen for a number of other the HWP categories.

Deforestation has increased, with land-use change to grasslands and croplands contributing to most of the increased emissions. DOM and living biomass make up a major part of the emissions from deforestation. Cropland remaining cropland drained organic soil is the largest emission source and has continued to increase on average from 1990 to 2022.

Reductions in emissions are small. 1990 to 2022 average declining trends are observed for the land-use change categories, wetland converted to cropland, forest land converted to settlements, forest land converted to cropland, and grasslands remaining grasslands.

It should be noted that single year comparisons between 1990 to 2022 do not provide a full picture of the overall trends. For example, deforestation results in large instantaneous emissions yet very few plots are observed per year. So large fluctuation in emissions will appear annually for many land-use change categories.

6.1.2.1 Annual variation in CO_2 removals on forest land

Forest land is the largest land-use category with the largest annual variation in CO_2 removals. The C stock in tree living biomass on forest land has increased throughout the inventory period (Figure 6.8).

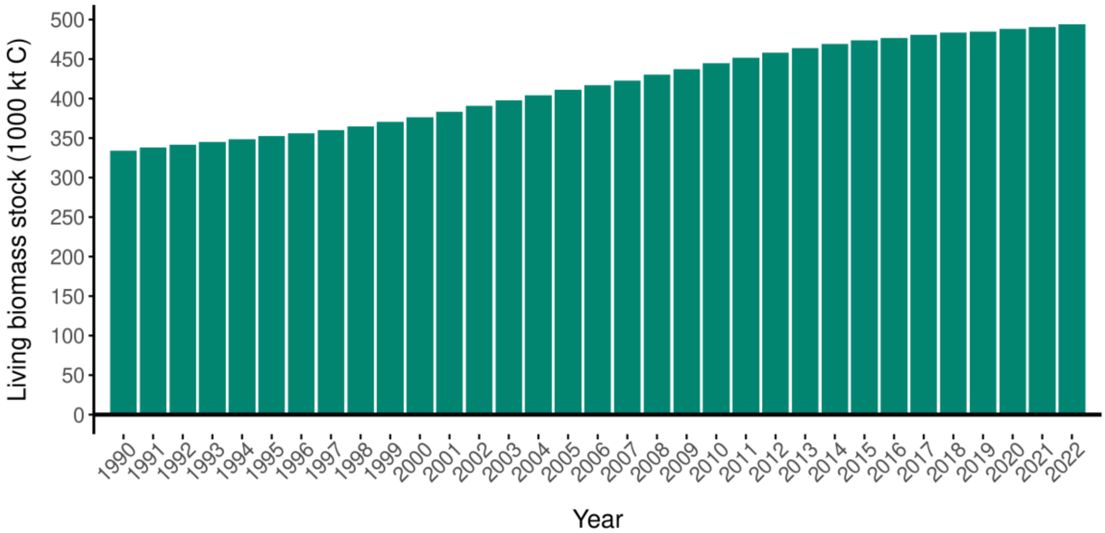


Figure 6.8: Development of the C stock in tree living biomass on forest land from 1990 -2022. Source: Norwegian Institute of Bioeconomy Research.

Since 1989, the C stocks in living biomass in the LULUCF sector have increased by around 46% (Table 6-2). This increase is mainly due to the increase in the growing stock of forest land.

Table 6-2: C stocks in 1989 and 2020 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	316 877	-	-
2020*	461 623	144 746	6

**The estimates are based on the last five years sampled in the National Forest Inventory (2018 – 2022). The estimate is, therefore, valid for mid-year 2020.*

The increase in C stock in tree living biomass since 1990 is caused by several factors. The net increment increased all the years until around the year 2000, and both annual increment (Figure 6.9) and net CO_2 removals (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. The increase in C stock in tree living biomass since 1990 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 47 million trees in 2022 (Statistics Norway 2023b). 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-calls 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.

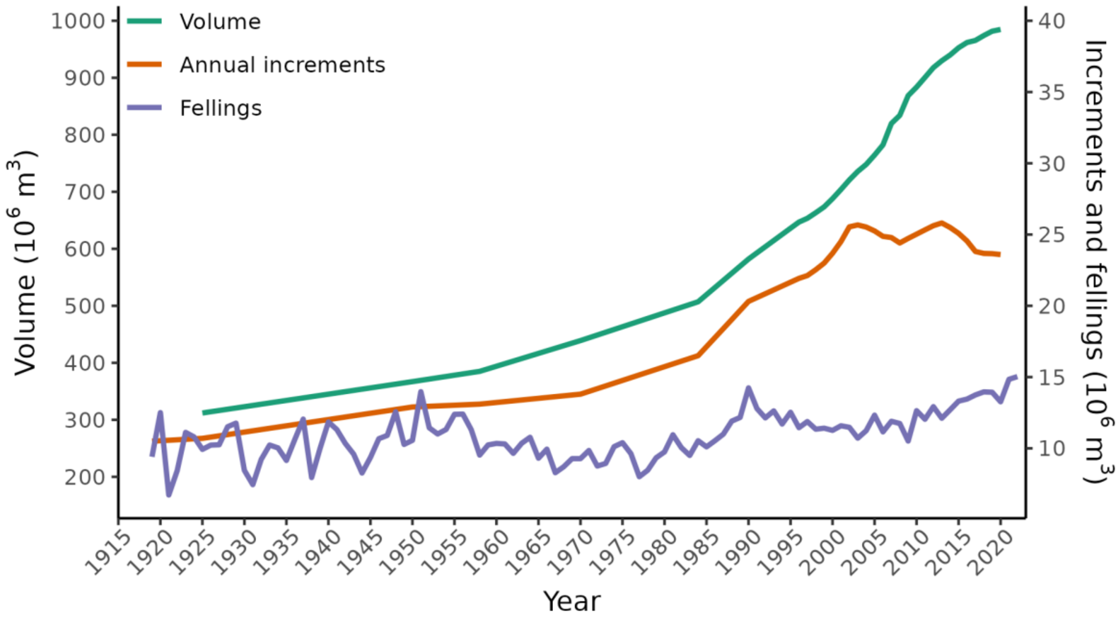


Figure 6.9: Forest fellings, annual increments, and volume (without bark) 1919 -2022. Source: Norwegian Institute of Bioeconomy Research and Statistics Norway.

6.1.2.2 Cumulative net emissions from land-use change from 1990 to 2022

Most emissions related to land-use change are the result of deforestation. Cumulative deforestation accounts for approximately 80 million tonnes of CO_2 equivalent, representing 95% of emissions related to land-use changes. Approximately 65% of deforestation emissions are from the loss of forest land to settlements. Most carbon removals are related to afforestation. Cumulative afforestation accounts for removals of approximately 22 million tonnes of CO_2, which is about 97% of the removals associated with land-use changes. Around 44% of afforestation is from grasslands to forest land and is largely due to the shift of the forest line further up in elevation with warmer temperatures, reduced outfield grazing, and the abandonment of land previously used as intensive grassland. See Figure 6.10 for an overview of the distribution of cumulative net emissions.

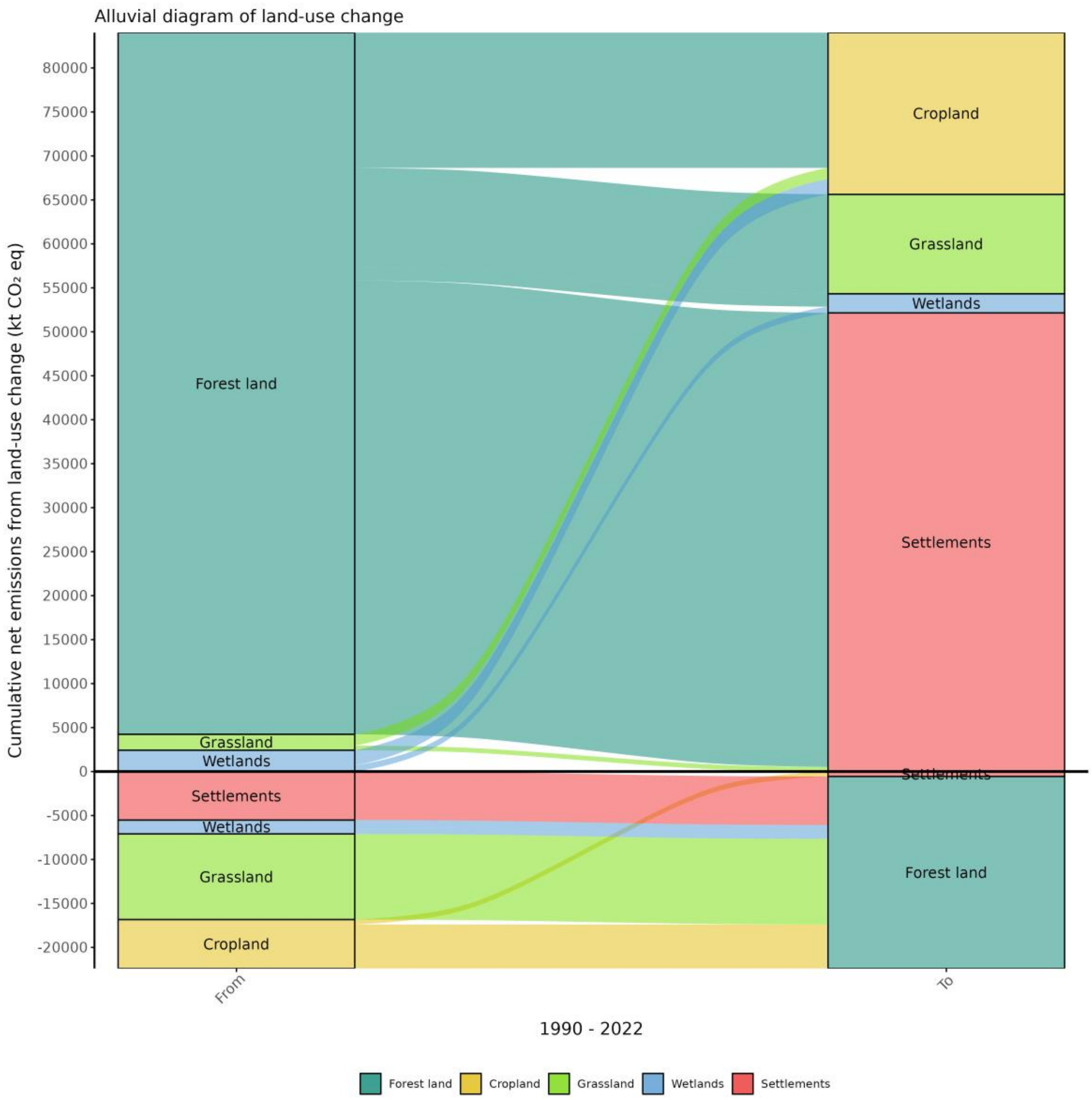


Figure 6.10: Distribution of cumulative net emissions and removals from land use transitions among IPCC land use categories from 1990 to 2022. Land-use changes with cumulative net emissions and removals less than 500 kt CO_2 equivalents are excluded from the figure as they are relatively small and not very visible. Source: Norwegian Institute of Bioeconomy Research.

6.1.3 Activity data

6.1.3.1 Data sources

Activity data is key for calculating emissions and removals in the Land Use, Land-Use Change, and Forestry (LULUCF) sector. The National Forest Inventory (NFI) provide estimates for forest land, cropland, grasslands, wetlands, and settlements. It also includes other land-use categories and land use changes between them. Supplementary data is provided by other sources and used to complement, enhance, or stratify estimates. These varied data sources help build the Greenhouse Gas (GHG) inventory for the LULUCF sector. Table 6-3 lists these sources, the data provided, and the categories they apply to.

Table 6-3: Data sources of the LULUCF GHG inventory

Data source	Data	Categories
National Forest Inventory (NFI)	Areas of various land categories and their sub-categories, and transitions between these land-use categories	Forest land, cropland, grasslands, wetlands, settlements, and other land
	Changes in Carbon (C) stocks in tree living biomass	Forest land, Grasslands, Wetlands and deforestation
	Carbon stocks in tree living biomass and mortality for modelling changes in the C stock in Yasso07	DOM and mineral soil for forest land remaining forest land
Statistics Norway	Forest fertilizers, sludge application, area per crop type, manure statistics, areas of orchards, harvest statistics, proportion of no-till cultivated pastures	Forest land, settlements, cropland, grasslands
Norwegian Food Safety Authority	Volume of peat and emission factor for calculating emissions (off-site)	Wetlands
Directorate for Civil Protection (DSB)	Number and area of forest fires	Forest land
FAO Forestry Statistics	HWP volumes for each category	HWP
Global Forest Change	Tree cover loss	Forest land
Norwegian Mapping Authority	Total land area of Norway	All land uses
SeNorge	Meteorological data for IPCC climate zones,	All land uses
	Meteorological data for FAO ecological zones	Forest land (to and from)
	Meteorological data for Yasso07 modelling	DOM and mineral soil for forest land remaining forest land

6.1.3.2 Land-use changes

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 2022 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 6.11).

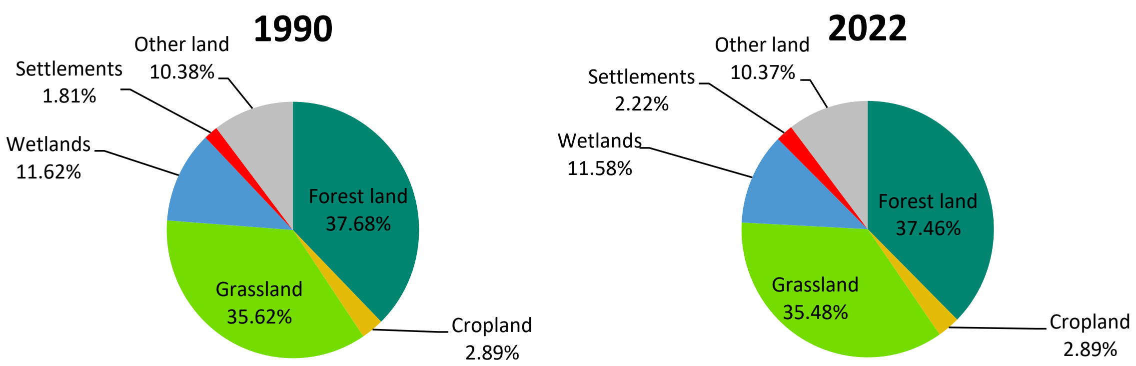


Figure 6.11: Area distribution of the IPCC land-use categories for 1990 and 2022. Source: Norwegian Institute of Bioeconomy Research.

The land-use changes are illustrated in
Figure 6.12 and shown in the land-use conversion matrix for the whole inventory period from 1990 to 2022 (Table 6-4). 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.

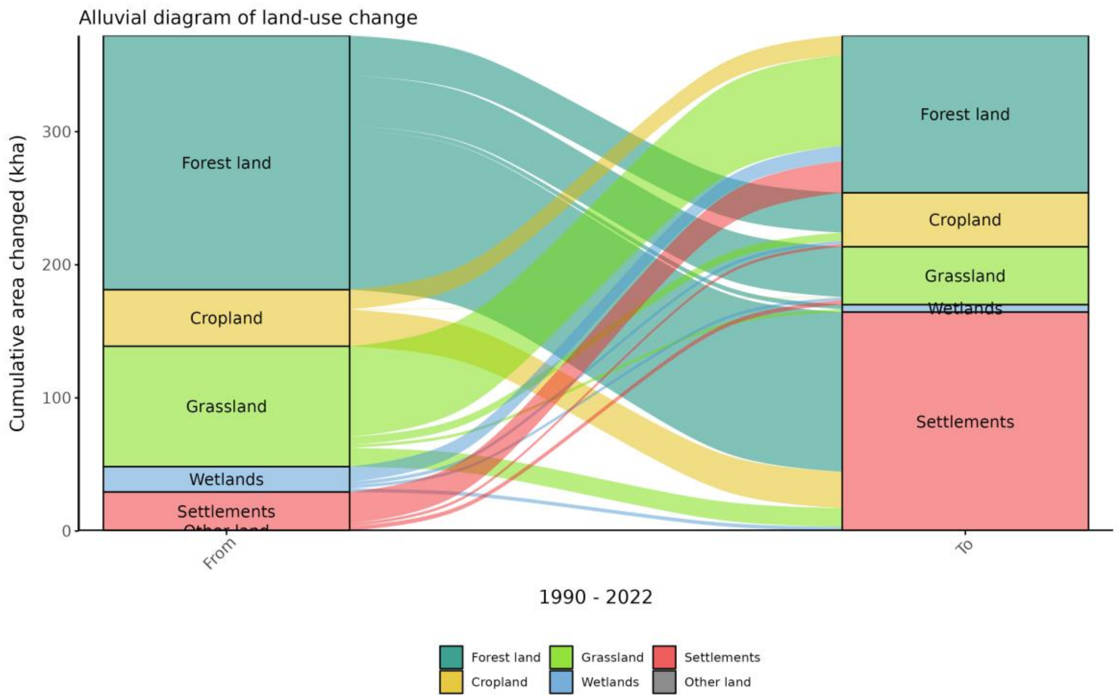


Figure 6.12: Distribution of cumulative area for land use transitions among all IPCC land use categories from 1990 to 2022. Source: Norwegian Institute of Bioeconomy Research.

Table 6-4: Land-use change matrix for the IPCC land-use categories from 1990 to 2022. 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	**2022**							
1990	Land-use	Forest land	Crop land	Grass land	Wet lands	Settle-ments	Other land	Total*
	Forest land	12 011	30	38	3	120	0	12 202
	Cropland	15	895	0	0	27	0	937
	Grassland	68	6	11 444	2	14	0	11 535
	Wetlands	12	3	2	3 745	3	0	3764
	Settlements	24	2	3	0	552	0	581
	Other land	0	0	0	0	0	3 359	3 359
	Total*	12 130	935	11 488	3 750	716	3 359	32 378

**Differences in totals and column or row sums are due to rounding.*

6.1.4 Uncertainties

See Annex 2 for a detailed description of uncertainties for the LULUCF sector.

6.1.5 Key categories

See chapter 1.4 for and overview of key categories for the LULUCF sector and its identification criteria.

6.1.6 Completeness

See chapter 1.7 for an overview of the LULUCF sector.

6.1.7 Quality assurance and quality control (QA/QC) for LULUCF

See Annex 4 for an overview of the QA/QC for the LULUCF sector.

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 6-5. 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).

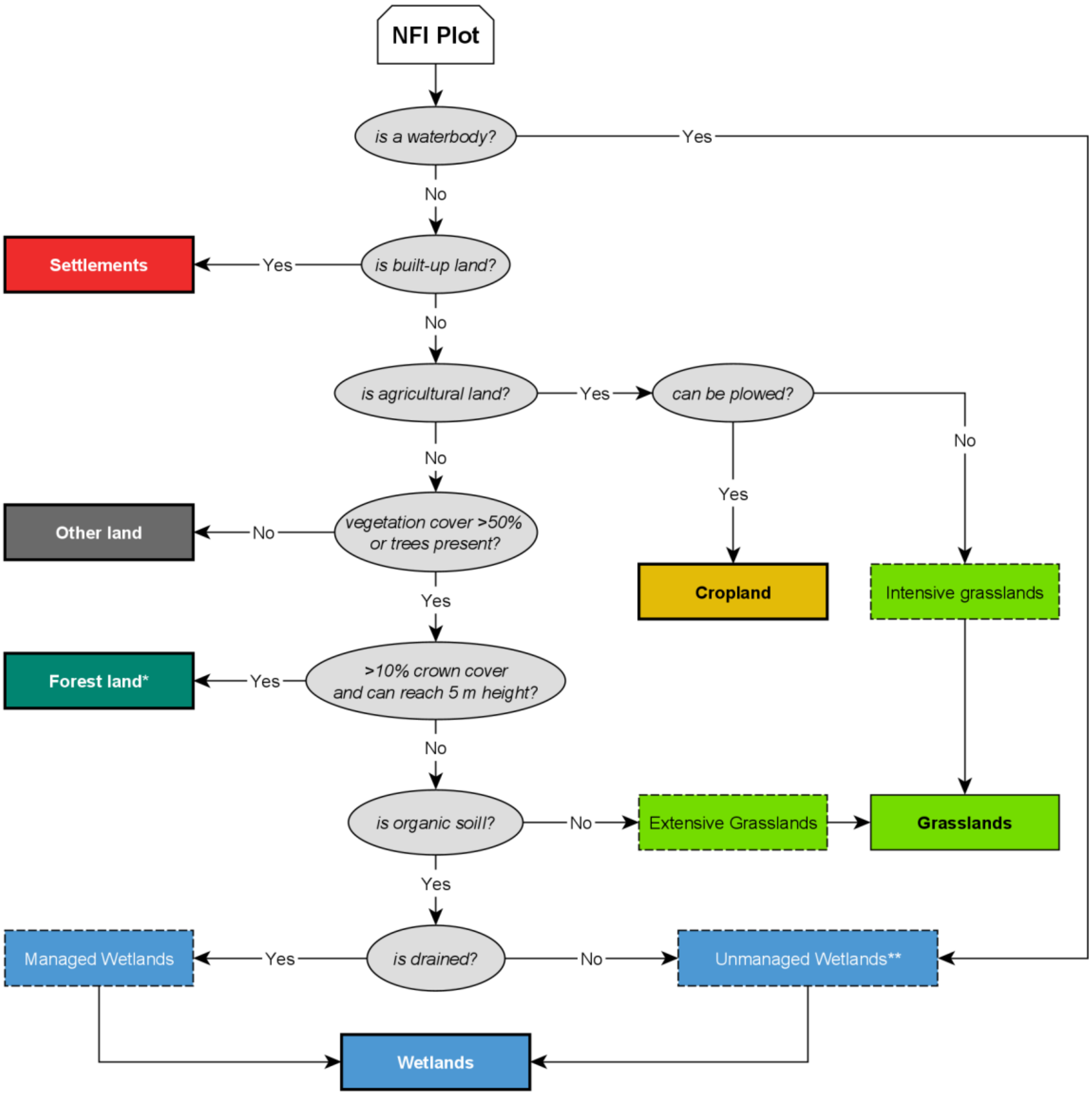


*Figure 6.13: Decision tree for land-use classification. An area will remain in a land-use category until it meets the criteria for another land-use category (e.g., cropland areas will remain in the cropland category even though abandoned as long as they do not meet the forest definition or otherwise 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. There areas are considered unmanaged in their totality.

Table 6-5: 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 usage / Land cover	Forestry, or no specific land usage	City, urban area Settlements of different kinds	Cabin area (5)	Recreation area	Military training field	Protected Area, Nature Reserve	Roads/Railroad Airport	Power line (6)	Other
Productive forest (1)	Forest land		Forest land	Forest land	Forest land	Forest land	Settlements	Settlements	Settlements
Non-productive forest (2)	Forest land	Settlements	Forest land	Forest land	Forest land	Forest land	Settlements	Settlements	Settlements
Other wooded land with crown cover 5-10% (3)	Grassland (extensive)	Settlements	Grassland (extensive)	Grassland (extensive)	Grassland (extensive)	Grassland (extensive)	Settlements	Settlements	Settlements
Other non-wooded areas (4)	Grassland (extensive)	Settlements	Grassland (extensive)	Grassland (extensive)	Grassland (extensive)	Grassland (extensive)	Settlements	Grassland (extensive)	Grassland (extensive)

Wooded mire, crown cover 5-10%	Wetlands	Settlements	Wetlands	Wetlands	Wetlands	Wetlands	Settlements	Settlements	Settlements
Coastal heath	Grassland (extensive)	Settlements	Grassland (extensive)	Grassland (extensive)	Grassland (extensive)	Grassland (extensive)	Settlements	Grassland (extensive)	Settlements
Bare rocks & glaciers	Other land	Settlements	Other land	Other land	Other land	Other land	Settlements		Settlements
Non-wooded mire	Wetlands		Wetlands	Wetlands	Wetlands	Wetlands	Settlements		Wetlands
Lakes and rivers (not sea)		Wetlands		Wetlands	Wetlands	Wetlands	Wetlands		Wetlands
Closed pasture grazing land, not regularly cultivated						Grassland (intensive)			Grassland (intensive)
Arable land, regularly cultivated						Cropland			Cropland
Other areas (4)	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 m^3 *ha^{-1} 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 m^3 *ha^{-1} 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 cm deep) and as wooded mire, if found on organic soil (organic layer > 40 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 forests in Norway are managed either for wood harvesting, protection (conservation of biodiversity and cultural heritage), protective purposes (reduction of damage risk to infrastructure and other land-uses from natural hazards), 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 forests in Norway are 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 6-6: Management status of different land-use categories. An area is only classified as belonging to one land-use category. 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 (6th NFI, 1986 – 1993). The land-use classes assessed in the 7th NFI (1994 – 1998) have been utilized for the corresponding plots in the 6th 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 6-4). 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.

6.2.3 Sink/source categories

Changes in C stocks are reported for the five main pools under the UNFCCC: living biomass (gains and losses), litter, dead wood, mineral soils, and organic soils. Litter and dead wood are summarized for all land-use classes, except for forest land, and reported as the dead organic matter pool. The pools are defined as follows:
Living biomass: For all land-use categories, except cropland, tree living biomass is defined as the biomass of living trees with a breast height diameter > 50 mm.

Table 6-7 describes which land-use categories tree living biomass is measured in the NFI. The tree biomass is the sum of the biomass estimates of the tree fractions stem wood, stem bark, living branches, dead branches, needles or leaves, stump, and roots down to a root diameter of 2 mm (see section 6.4.1). On cropland remaining cropland, C stock changes in perennial tree living biomass are calculated on areas with fruit trees. In addition, other non-woody forms of living biomass exist, such as the biomass of herbaceous plants, grass living biomass, and annual crop living biomass which are considered in the case of land use changes.

Table 6-7: Measurements of tree parameters in the NFI given Norwegian land cover (No. Arealtype) and land-usage (No. Arealanvendelse) classes. Green cells indicate the measurement of trees (a = measurements since 2007, and b = measurements since 2010). Grey cells indicate that trees are not measured on that land-use class. Not all land use and land cover combinations exist (see Table 6-5).

Land cover	Land usage								
	Forestry (no other use or restrictions)	City urban area Settlements of different kinds	Cabin area	Recreation area	Military training field	Protected Area, Nature Reserve	Roads, Railroad, Airport	Power line	Other
Productive forest land (1)								b	
Non-productive forest land (2)								b	
other wooded land, crown cover 5-10% (3)								b	
Non-wooded, mineral soil								b	
Wooded mire, crown cover 5-10%								b	
Coastal heath								b	
Bare rocks and soil								b	
Mire without tree cover									
Lakes and rivers (not sea)									
Grazing land, not regularly cultivated	a	a	a	a	a	a	a	a	a
Arable land, regularly 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 (2015). So far, the soil survey covers only 59% of all croplands and 7% of all intensive grasslands. The remaining non-covered area for cropland (41%) and intensive grasslands (93%) classification were derived from the national land resource map AR5[42] 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 (

[42] http://kilden.skogoglandskap.no/?topic=arealinformasjon&layers=ar5_bonitet&X=7260874.41&Y=125323.37&zoom=0&lang=nb&bgLayer=graatone_cache&layers_opacity=0.75

Table 6-8), the general term “organic soil” used consistently throughout this report refers to the three definitions mentioned above.

Table 6-8: 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%
NFI	Forest, other wooded land and wooded mires	≥ 40cm	-
National soil survey	59% cropland 7% intensive grassland	≥ 40 cm	≥ 10%
AR5	41% cropland 93% intensive grassland	≥ 20 cm	-
WRB (Histosol)	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. 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 1/5th of the sample plots evenly distributed throughout the country (the so-called "panel") using a Latin square design are measured yearly. The same plots are re-sampled in a 5-year cycle, and all plots are assessed during a 5-year period. The Norwegian Institute of Bioeconomy Research (NIBIO) operates the NFI. Inventory work was started in 1919 with regular inventory cycles. 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. The 12th 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 6.14). 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 6.15).

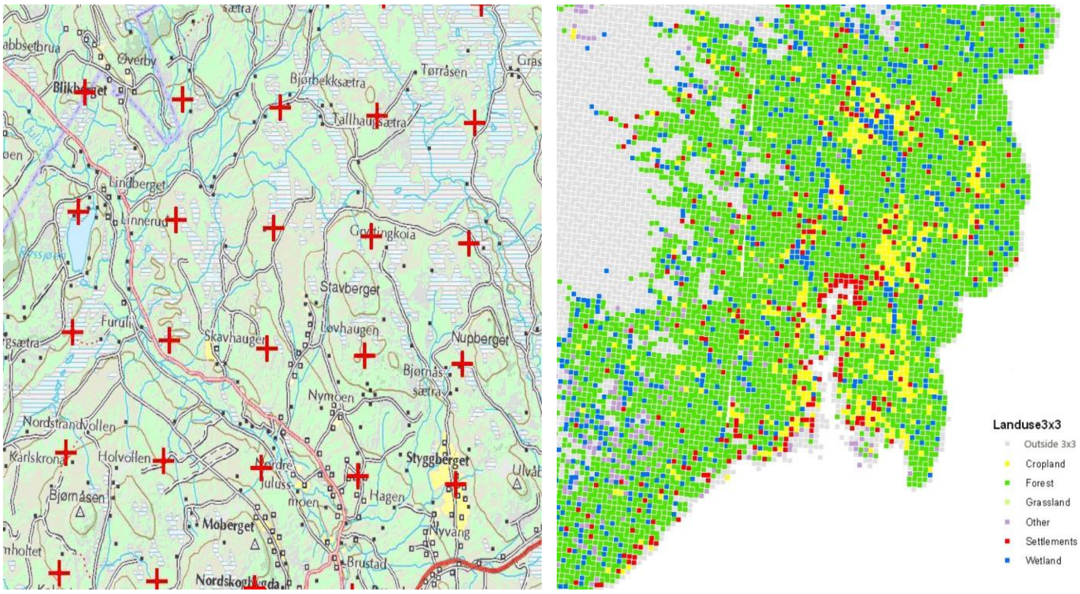


Figure 6.14: The sample plots cover all land-use categories. Plots are placed in the systematic 3x3 km grid in the example map to the left. On the right-hand side, we see the distribution of land use-categories in the southeastern part of Norway below the coniferous tree line (only 3x3 grid).

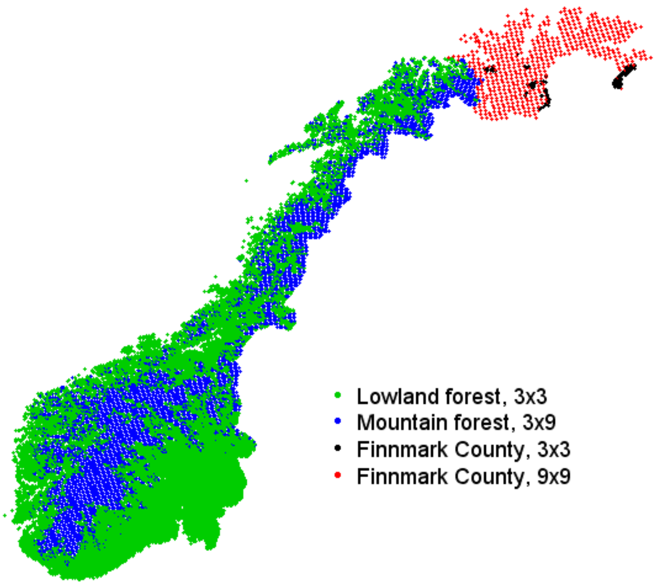


Figure 6.15: Spatial distribution (approximate locations) of the NFI sample plots in the four strata. The sample plots in Finnmark county located on the 3x3 km grid cover lowlands, while the sample plots on the 9x9 km grid cover mountainous areas.

As can be seen from the estimate of all land-use categories for 2010, most of the tree living biomass stock is allocated in the lowland forests outside Finnmark, followed by the mountain forest outside Finnmark, the mountain forest in Finnmark county, and the lowlands in Finnmark (Table 6-9).

Table 6-9: 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
Lowlands outside Finnmark	14 989	423 533	2.9	94.3
Mountain forest outside Finnmark	12 528	16 738	12.3	3.7
Lowlands in Finnmark	135	1 773	21.4	0.4
Mountain forest in Finnmark	4 727	7 164	24.9	1.6
All	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 ≥ 50 mm are recorded on circular sample plots with a radius of 8.92 m (250 m^2). 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 (NFLI 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 6-10.

Table 6-10: Area representation of Norway's IPCC climate regions based on NFI plots.

IPCC climate region	Area representation	
	(kha)	(%)
Boreal Dry	862	2.66
Boreal Moist	4 805	14.84
Cool Temperate Dry	273	0.84
Cool Temperate Moist	22 432	69.28
Polar Dry	5	0.02
Polar Moist	4 001	12.36
Total	32 378	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[43] (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).

[43] 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 public through the web portal 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 7% 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[44]. 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 6.16 displays Norway's land uses and stratification by overall soil type, IPCC climate region, and FAO ecological zones.

[44]http://kilden.skogoglandskap.no/?topic=arealinformasjon&layers=ar5_bonitet&X=7260874.41&Y=125323.37&zoom=0&lang=nb&bgLayer=graatone_cache&layers_opacity=0.75

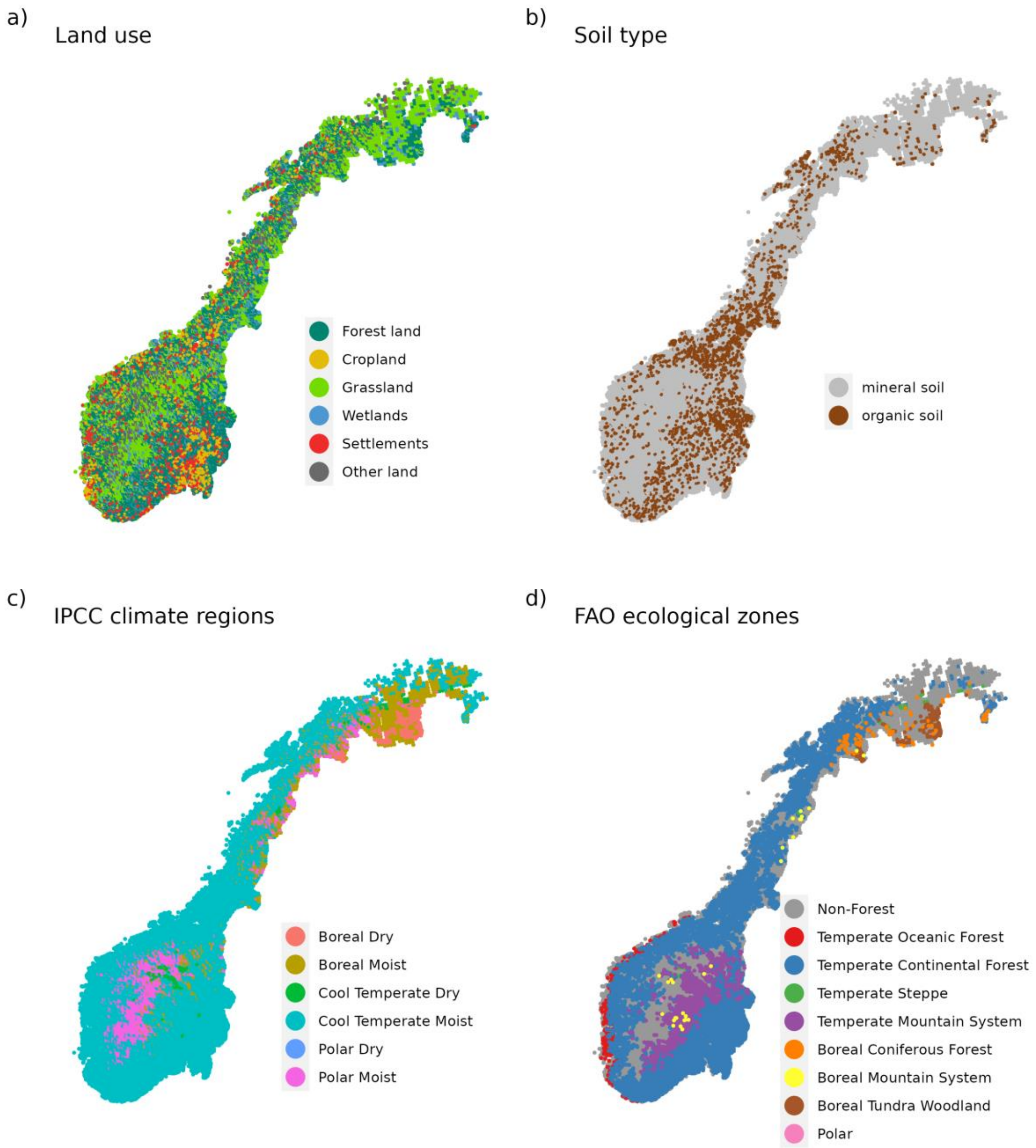


Figure 6.16: Map overview of NFI plot stratification: a) Land use categories as of 2005 to 2022; b) soil types; c) IPCC climate regions; d) FAO ecological zones for forest lands. The visual representation of each plot on the maps is altered to ensure the visibility of all categories, as the plotting 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^2. However, in the inventory period between 1986 and 1993, concentric sample plots were used in some counties. All trees with a DBH >= 50 mm were measured on a circular sample plot with an area of 100 m^2. 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^2 in Østfold, Akershus, Oslo, and Nord-Trøndelag counties, whereas the area was 250 m^2 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^2.

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^2). 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 6-5) 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 $m^3\ ha^{-1}\ yr^{-1}$ 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 1/5th of all 22 008 sample plots. Panel #1 was installed[45] 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. The sample plot time interval between the first measurements (1986-1993) and the second measurement (1994-1998) results in different time intervals for each plot ranging from 1 to 12 years.

All estimates are based on linear interpolation of areas and C stocks between plot-wise observations that are then aggregated to 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, area estimates were extrapolated based on the last two estimates per plot. This way, the rate of land-use change area is projected based on the area observations of the last 10 years for each plot (Figure 6.17).

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 6.17). 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.

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.

[45] 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.

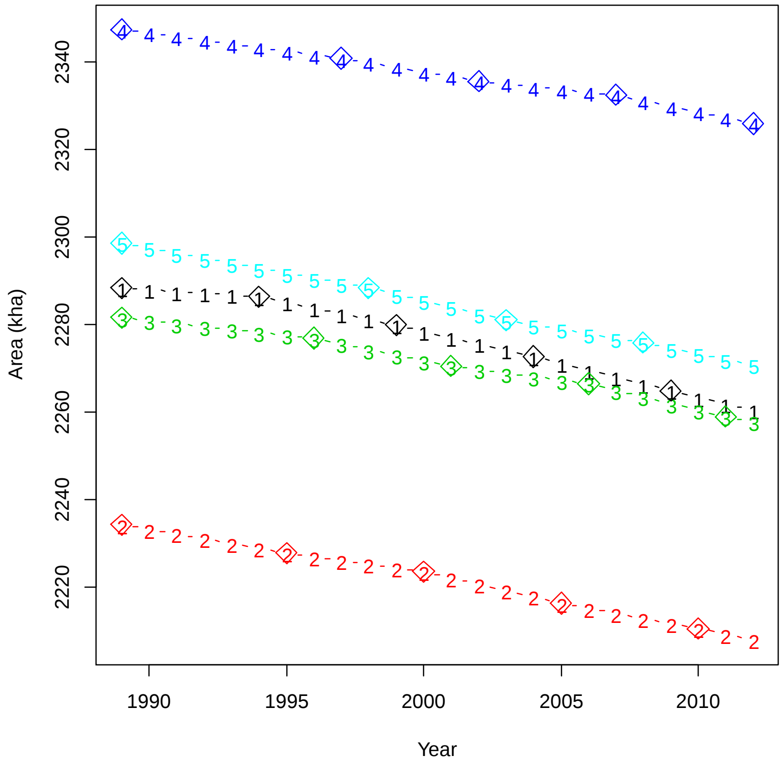


Figure 6.17: Estimated forest land remaining forest land area covering mineral soils within the five NFI panels illustrated with data from 1989 until 2012. Diamonds indicate the measurement year of the sample plots in the respective panel (1 – 5). The estimated area was the sum of interpolated plots 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 6.17) is the sum over all i=1,..., 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).

The majority of carbons stock change (CSC) emissions and removals are calculated for each plot individually (Approach 3). This means that emissions and removals are calculated for the time intervals for each NFI observation (See section 6.3.1on NFI design). During the final steps of the emission and removals calculations, the emission / removals estimates for each plot is converted to emission / removals per ha per year for the timeseries. This dataset is combined with the plot-wise area inter-extrapolation dataset to produce annual plot-wise emissions and removals for the timeseries. This dataset is then aggregated to national level estimates.

For living biomass, the approach is slightly different: For each plot, living biomass gains and losses are calculated for each year there is an NFI observation. The change of living biomass carbons stock change (gains or losses) within a land-use class in a given measurement year (green diamonds in Figure 6.18) is the sum of changes over all sample plots within a panel

$$c_{LUC} = \sum_i p_{LUC,i} rf_i \, c_{LUC,i}$$

where $c_{LUC,i}$ is the mean annual change of the living biomass carbons stock change 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. The estimates are interpolated and extrapolated directly from the estimated living biomass change (i.e. the method does not require the area inter-extrapolation dataset). Linear interpolation of stocks means constant changes (gains and losses) between two measurements.

However, for extrapolation of clearcut harvests / deforestation additional surrogate data are used to improve the interpolated and extrapolated estimates for living biomass losses. The surrogate data are the remote-sensing product Global Forest Change (GFC) (Hansen 2013), which is used to determine which NFI plots have been harvested / deforested in the last 5 years, to help estimate biomass loss for plots that have not yet been surveyed in the last five years int the by field. By using the historic NFI data to estimate the fraction of living biomass loss after harvest or deforestation, estimates of the living biomass loss can be calculated for the plots where GFC has detected tree cover loss.

It is currently not possible to differentiate whether plots have tree cover loss due to clearcuts related to harvests or deforestation. To differentiate between loss from harvest (forest land remaining forest land) and deforestation (forest land converted to other land use types), living biomass loss rates (based on the last 5 years) for each of the land-use changes are used to distribute the clearcut living biomass losses by the GFC extrapolation technique.

For the losses associated with natural mortality, thinning and other harvest (small scale harvest, not classified as clearcut harvest or thinning), living biomass loss rates for the last five years for each plot are used to extrapolate for the years without observations. It is assumed that due to the spatial resolution constraints of GFC product, the tree cover loss in most cases of natural mortality and other harvest will not be detected. As such, using the 5-year average rate for these categories is still considered more reliable. For extrapolation of living biomass gains, the last 5 years average rate is used.

Since both gains and losses are observed on a 5-year basis for each plot (with exception during 1986-1998), both the annual rate of gains and losses for each plot is constant between two observations. To reflect the annual variability in harvests and deforestation, the interpolated and extrapolated biomass losses due to clearcuts have been adjusted for the actual year of the fellings on each plot. The years of the fellings are determined by the fieldworkers on-site but is later checked and possibly adjusted when comparing with aerial and satellite imagery. Between the first field observations (1986-1993) and the second field observations (1994-1998) the time intervals can be as large as 12 years for some plots. For this reason, on-site estimated felling year between the first and second observation are considered unreliable, and national harvest statistics provided by Statistics Norway[46] are used to produce the annual variability. For the extrapolated period the GFC year is used to determine the year of felling. The result of redistributing the inter-extrapolated losses is an increase in capturing the annual variability of carbon change related to clearcuts. For losses associated with thinning, other harvest and natural mortality, no adjustment in annual variability is applied to each plot. See Figure 6.18 for a workflow diagram illustrating the processing steps from interpolation-extrapolation to aggregation.

[46] The harvest statistics are based on Tables 06964 and 03795 (Statistics Norway 2022a), 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 2022c) and Trond Amund Steinset - Statistics Norway (Personal communication, 2020).

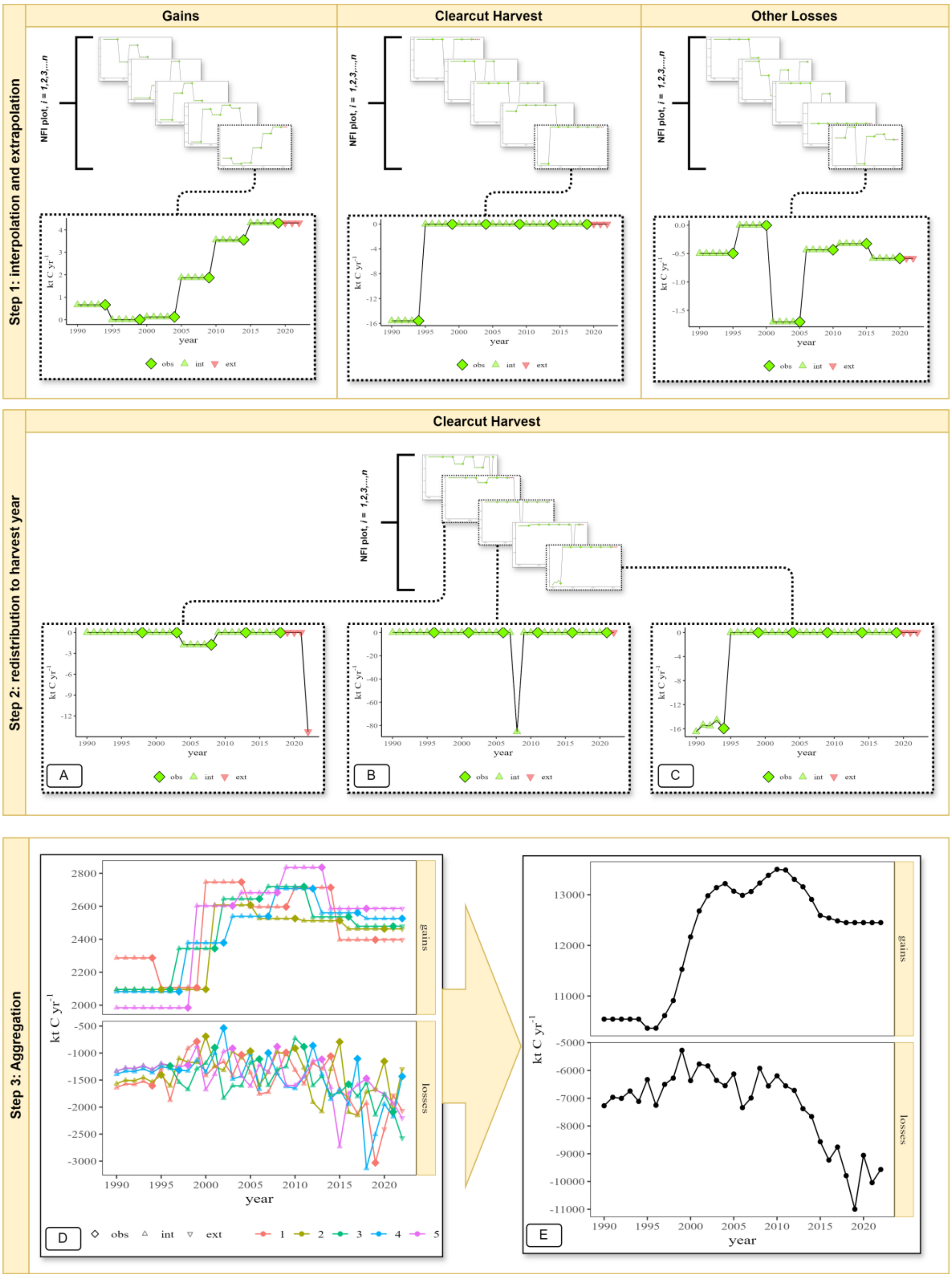


Figure 6.18: Workflow of interpolation-extrapolation processing steps. Step 1: linear interpolation (green triangles) are applied to observation (green diamonds) gains and losses for each NFI plot between each observation (green diamonds). Extrapolation (red upside-down triangle) is the average of the last 5 years (gains and other losses), except for plots with observed clearcut harvest in the time series, either from NFI registrations or Global Forest Change (GFC). In case of GFC detected loss, estimated biomass loss is calculated for the plot in the extrapolation

period. Step 2: Living biomass losses associated with clearcut on a plot are redistributed from the interpolated or extrapolated period to the specific year of loss. Different examples are given for loss redistribution: A) the loss is in the extrapolation period and GFC year is used; B) the loss is in the interpolation period and NFI registered harvest year is used; C) the loss is in the interpolation period between the first and second NFI observation in the beginning of the time series (before 1995-1999 depending on the NFI panel) and harvest statistics from Statistics Norway (SSB) is used. Step 3: The interpolated-extrapolated values for each plot are aggregated: D) individual NFI plots are aggregated to their respective panel, illustrating living biomass stock change estimates for each panel (coloured points and lines). E) illustrates the final national aggregation over all 5 panels.

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, a number 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[47] 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 extrapolate 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 required, 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

[47] 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.

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).

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[48]. Table 6-11 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 6-11: Total LULUCF GHG emissions (kt CO_2 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

[48] 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).

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

6.3.7 Uncertainties in areas and living biomass estimates

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, ..., 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,..., n_h.
The estimated variance of the proportion is given by

$$var(p_h) = \frac{s_h^2}{n_h}$$

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

$$var(A_{LUC}) = A\sum_h \left(\frac{N_h}{N}\right)^2 var(p_h).$$

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

$$var(T_h) = N_h^2 \frac{s_h^2}{n_h}.$$

The total biomass gain or loss estimate (T) over all strata and its variance (var(T)) is the sum over T_h and 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

$$U(T) = \frac{2\sqrt{var(T)}}{T}100$$

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 37% of the area of Norway. Forest ownership in Norway is dominated by private ownership, with many small properties. In 2022 there were 126 125 forest holdings with more than 2.5 ha of productive forest land in Norway (Statistics Norway 2023a). 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 carbon removal in Norway.

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. Details on identification criteria can be found in chapter 1.4.

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_2 removals from the atmosphere.

The stock change method is used to quantify these changes. 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. 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 6-12 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 6-12: 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. Details on identification criteria can be found in chapter 1.4.

For forest land remaining forest lands on mineral soils, a model approach is used. The model used, Yasso07, to estimate C stock changes in mineral soils (see below) provides a change estimate for total soil organic carbon (SOC), which includes the dead organic matter (dead wood, litter) and soil pools. The annual fluctuation seen in CO_2 sequestered in dead organic matter (DOM), and mineral soil 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 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 (Table 6-13). Only the changes in the H pool (humus; Table 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.

Table 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

<table>
<tr><th>Origin</th><th colspan="5">Aboveground</th><th colspan="5">Belowground</th></tr>
<tr><td>Chemical component</td><td>A</td><td>W</td><td>E</td><td>N</td><td>H</td><td>A</td><td>W</td><td>E</td><td>N</td><td>H</td></tr>
<tr><td>Non woody</td><td colspan="9" rowspan="2">LITTER</td><td rowspan="3">SOIL</td></tr>
<tr><td>Fine woody</td></tr>
<tr><td>Coarse woody</td><td colspan="9">DEAD WOOD</td></tr>
</table>

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. Details on identification criteria can be found in chapter 1.4.

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, L. et al. (2016). Yasso07 represents processes for mineral soils down to a depth of 1 m and operates using five chemical soil C pools (Figure 6.19). Decomposition (CO_2 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.

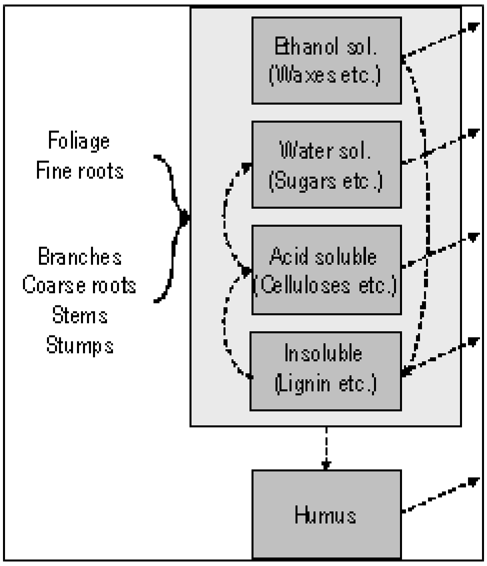


Figure 6.19: Flow diagram for chemical soil C pools in Yasso07. Fluxes significantly different from 0 are indicated by the arrows (Liski et al. 2009).

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 6-14), and annual turnover rates for roots, foliage and branches were applied to estimate the annual C input (Table 6-15 and Table 6-16).

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, only when observations from the NFI plots are absent. Data from the 8th NFI (2000 – 2004) and the 9th 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 1951 (model-input-backcast).

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 1951 – 1985 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 6-14: 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
Dead branches	Marklund (1988), G20, T22, Smith et al. (2014) birch/deciduous
Living branches	Marklund (1988), G12 and G16, T14 and T18, Smith et al. (2014) birch/deciduous
Foliage	Marklund (1988), G20, T22, 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 (for Scots pine), Smith et al. (2016) birch/deciduous[a]
Roots (> 5 cm)	Marklund (1988), G28, T31, Smith et al. (2016) birch/deciduous[a]
Roots (2 mm–5 cm)	Petersson and Ståhl (2006), B*i* (for Norway spruce, Scots pine) Marklund (1988), G28, G26, T31, T28, Smith et al. (2014) birch/deciduous[a]
Roots (< 2 mm)	0.3 × foliage biomass; (Kjønaas et al. Manuscript)

[a] No distinct diameter limit is inferred between the two classes of deciduous coarse roots.

Table 6-15: 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
Foliage	0.143	0.33	1	Tierney and Fahey (2002)
Live and dead branches, roots > 2 mm	0.0125	0.027	0.025	Muukkonen and Lethonen (2004) DeAngelis et al. (1981) Lehtonen et al. (2004)
Roots < 2 mm	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 6-16) can be found in Peltoniemi et al. (2004).

Table 6-16: Annual turnover rates for litter from ground vegetation.

Component	Moss	Lichens	Herbs and grasses	Shrubs
Aboveground	0.33	0.1	1	0.25
Belowground	-	-	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 6-17).

Table 6-17: The fraction of C input made up of acid soluble (A), water soluble (W), ethanol soluble (E), and insoluble (N).

Component[a]	A	W	E	N
Stem **Norway spruce** **Scots pine** **Deciduous**	 0.63, 0.7 0.66, 0.68 0.65, 0.78	 0.03, 0.005 0.03, 0.015 0.03, 0	 0, 0.005 0, 0.015 0	 0.33, 0.28 0.29, 0.28 0.32, 0.22
Roots (<2mm) **Norway spruce** **Scots pine** **Deciduous**	 0.5508 0.5791 as foliage	 0.1331 0.1286 as foliage	 0.0665 0.0643 as foliage	 0.2496 0.228 as foliage
Foliage **Norway spruce** **Scots pine** **Deciduous**	 0.4826 0.5180 0.4079, 0.46	 0.1317 0.1773 0.198, 0.1929	 0.0658 0.0887 0.099, 0.0964	 0.3199 0.2160 0.2951, 0.2507
Living and dead branches **Norway spruce** **Scots pine**[b] **Deciduous**	as stem 0.3997-0.5307 as stem	as stem 0.0105-0.0295 as stem	as stem 0.0382-0.1309 as stem	as stem 0.411-0.4608 as stem
Roots > 2 mm	as branches	as branches	as branches	as branches
Stumps	as stem	as stem	as stem	as stem
Bark	as foliage	as foliage	as foliage	as foliage
Ground vegetation[c] **Moss** **Lichens** **Herbs and grasses** **Shrubs**	 0.74 0.836 0.27 0.56	 0.0867 0.0747 0.4667 0.2067	 0.0433 0.0373 0.2333 0.1033	 0.13 0.052 0.03 0.13

[a] The majority of values are from the Yasso07 user manual (Liski et al. 2009). [b] 25 observations were available. The range is given. [c] 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 6-18.

Table 6-18: Mean values for C input and predicted soil C (distributed by litter pools). Each entry is weighted by its appropriate NFI area weight (which differ among the NFI strata).

Category	Non-woody	Fine-woody	Coarse-woody	Total
C input (tC* ha^{-1} yr^{-1}*)				
Ground vegetation	0.40			0.40
Tree living biomass	0.87	0.22		1.09
Natural mortality	0.01	0.08	0.06	0.15

Commercial harvest	0.03	0.13	0.04	0.20
Other harvest	0.01	0.04	0.01	0.06
Total	1.32	0.47	0.11	1.90
Equilibrium stock (tC* ha^{-1}*)				
Ground vegetation	9.95			9.95
Tree living biomass	26.13	6.68		32.81
Natural mortality	0.39	2.25	3.88	6.52
Commercial harvest	0.83	3.57	2.58	6.97
Other harvest	0.26	1.22	0.74	2.22
Total	37.55	13.72	7.20	58.48
Predicted stock* (tC* ha^{-1}*)				
Ground vegetation	9.77			9.77
Tree living biomass	26.91	6.76		33.67
Natural mortality	0.40	2.30	4.02	6.72
Commercial harvest	0.92	3.90	2.75	7.56
Other harvest	0.26	1.25	0.74	2.25
Total	38.27	14.19	7.51	59.97

Across all entries in the time-series, excluding backcast entries.

For each NFI plot, start values for the five chemical C pools (Figure 6.19) 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[49] 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 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^{-2}. 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.

[49] 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).

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 – 2022.

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.

<u>Activity data</u>

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 2018-2022 revealed an area of 469 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.

<u>Assumptions/justification</u>

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 (belowground) (see Table 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, 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. Details on identification criteria can be found in chapter 1.4.

CO_2 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.

<u>Activity data</u>

Ditch records on the national scale are available from the 1950s (Statistics Norway, 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^{-1} in the early 1960s. Since then, establishing drainage ditches to facilitate forest production became much less practiced, 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 2018-2022, 133 kha of ditched area were recorded in the Norwegian NFI, and these records were used as activity data for emissions from drained organic forest soil (as well as for CO_2 in Wetlands (section 6.7) and non-CO_2 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_2 emissions (IPCC 2014).

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_2 yr^{-1} ha^{-1}, 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 14% 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 Annex 2.

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 2024) 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 6-19) to uncertain parameters to predict possible outcomes.

Table 6-19: Characteristics of the parameters used in the Monte Carlo simulations.

Parameter		Distribution†	Mean	Standard deviation	References
AWEN chemical composition (%)	Branch - pine	Normal	47.3; 1.9; 7.9; 43 [a]	3.7; 0.6; 2.9; 1.4 [a]	Expert judgment means and standard deviation (SD) are calculated from values in Table 6-17. For means based on a single value, SD is calculated for each component by calculating the mean relative standard deviation (RSD) for AWEN grouped by the woodiness category: non-wood, fine-woody, and coarse wood.
	Leaf – spruce		48.3; 13.2; 6.6; 32 [a]	4.3; 0.3; 0.1; 3.8 [a]	
	Leaf – pine		51.8; 17.7; 8.9; 21.6 [a]	4.7; 0.4; 0.2; 2.6 [a]	
	Leaf – birch		43.4; 19.5; 9.8; 27.3 [a]	3.7; 0.4; 0.2; 3.1 [a]	
	Stem – spruce		67.2; 1.8; 0.3; 30.8 [a]	4.9; 1.8; 0.4; 3.5 [a]	
	Stem – pine		68; 2.3; 0.8; 28.9 [a]	1.4; 1.1; 1.1; 0.7 [a]	
	Stem – birch		71.5; 1.5; 0; 27 [a]	9.2; 2.1; 0; 7.1 [a]	
	Fine root – spruce		55.1; 13.3; 6.7; 25 [a]	5; 0.3; 0.1; 3 [a]	
	Fine root – pine		57.9; 12.9; 6.4; 22.8 [a]	5.2; 0.3; 0.1; 2.7 [a]	
	Lichens		83.6; 7.5; 3.7; 5.2 [a]	7.5; 0.1; 0.1; 0.6 [a]	
	Moss		74; 8.7; 4.3; 13 [a]	6.7; 0.2; 0.1; 1.6 [a]	
	Herbs and grasses		27; 46.7; 23.3; 3 [a]	2.4; 0.9; 0.5; 0.4 [a]	
	Shrubs		56; 20.7; 10.3; 13[a]	5; 0.4; 0.2; 1.6 [a]	
Fine woody litter dimension (cm)		Log-normal	ln(2) = 0.69[d]	(ln(6)-ln(0.2))/2 = 1.70[d]	Expert judgment
Coarse woody litter dimension (cm)		Log-normal	ln(10) = 2.30[d]	(ln(12)-ln(8))/2 = 0.20[d]	Expert judgment
Branch and coarse root turnover (yr^{-1})		Normal	0.0125; 0.027; 0.025[b]	20%; 25%[c]	Peltoniemi et al. (2006); expert judgment
Fine root turnover (yr^{-1})		Log-normal	ln(0.6) = -0.51[d]	0.3[d]	(Brunner et al. 2013) (Hansson et al. 2013); expert judgment
Foliage turnover (yr^{-1})		Normal; uniform[c]	0.143; 0.33; 0.9-1.0[b]	15%	Peltoniemi et al. (2006); expert judgment

Ground vegetation turnover (yr^{-1})	Normal	0.33; 0.1; 1.0; 0.25 (aboveground)[e] 0.33; 0.33 (belowground)[f]	40%	Peltoniemi et al. (2006)
Fineroot to foilage biomass ratio	Normal	0.3	50%	Expert judgement. A conservative estimate of uncertainty based on , Finér (2011); Härkönen (2011), and Yuan (2010)
Biomass ratio for ground vegetation, below-to-above	Normal	2	20%	Peltoniemi et al. (2006)

[†]Distributions for AWEN fraction and woody size are truncated by excluding random values from the distribution that are negative. Truncation for turnover rates is also applied, where negative values and zero are excluded. [a]Acid, water, ethanol, and non-soluble, respectively. [b]Spruce, pine and deciduous, respectively. [c]Conifers and deciduous, respectively. [d]natural log-transformation. [e]Moss, lichens, herbs/grasses and shrubs, respectively. [f]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, or log-normally distributed, and negative values were avoided by truncated distributions (resampling when negative values are drawn from the random distribution). Uncertainty was derived from the 2.5th and 97.5th percentile of the 1000 simulations (Figure 6.20). The result was an uncertainty estimate of the Yasso07 simulated C stock changes of 32.6% in 2022, which applied to both the DOM and mineral soil pools.

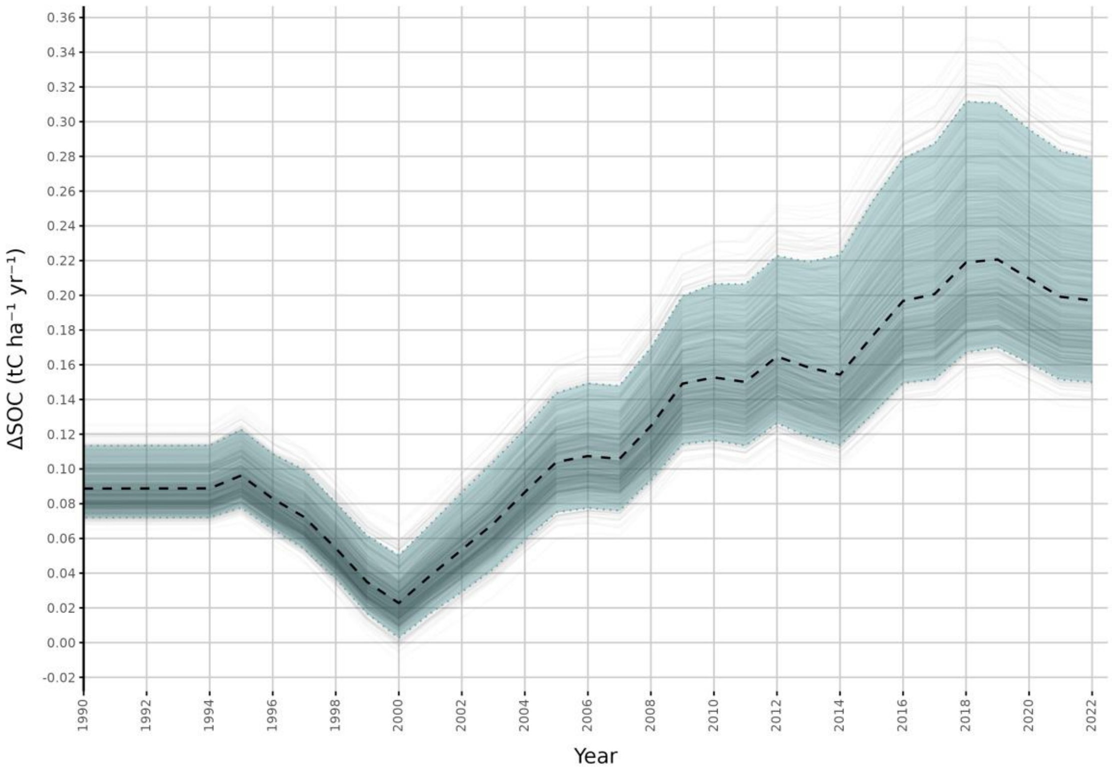


Figure 6.20: Uncertainty for C stock change for SOC derived Monte Carlo simulations (n = 1000, faint grey lines). The cyan band indicates the 95% confidence interval derived for each year from the 2.5th and 97.5th percentile of the 1000 simulations. The dashed line indicated the mean of the 1000 simulations.

Uncertainties in the biomass models (Table 6-19) 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 Supplement were applied, and uncertainties of the areas were estimated by sample error (see Annex 2).

6.4.1.2.4 Verification

<u>Litter, dead wood and mineral soil using Yasso07</u>

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, L. et al. 2016). 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, L. et al. 2016)

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 (Lange et al. (2017), Kjønaas 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^{2}yr; aggregated to national scale) are within the range found for neighboring countries (Dalsgaard et al. 2017):
    - Finland (11-12 g C/m^{2}yr) (measurements, (Rantakari et al. 2012); and the Finnish GHG inventory 2014 for the DOM and SOC pools)
    - Sweden (18-20 g C/m^{2}yr) (SOC + DOM in the GHG inventory 2014)
    - Sweden (12-13 g C/m^{2}yr and 6-7 g C/m^{2}yr) (model estimates 1926-2000 using two alternative models; (Ortiz et al. 2013; Ågren et al. 2008)

- Sweden (25 g C/m^{2}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 6.21) and, after changing climate input to Yasso07 from long term averages to 5-year averages, NIR 2021, 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 6.21).

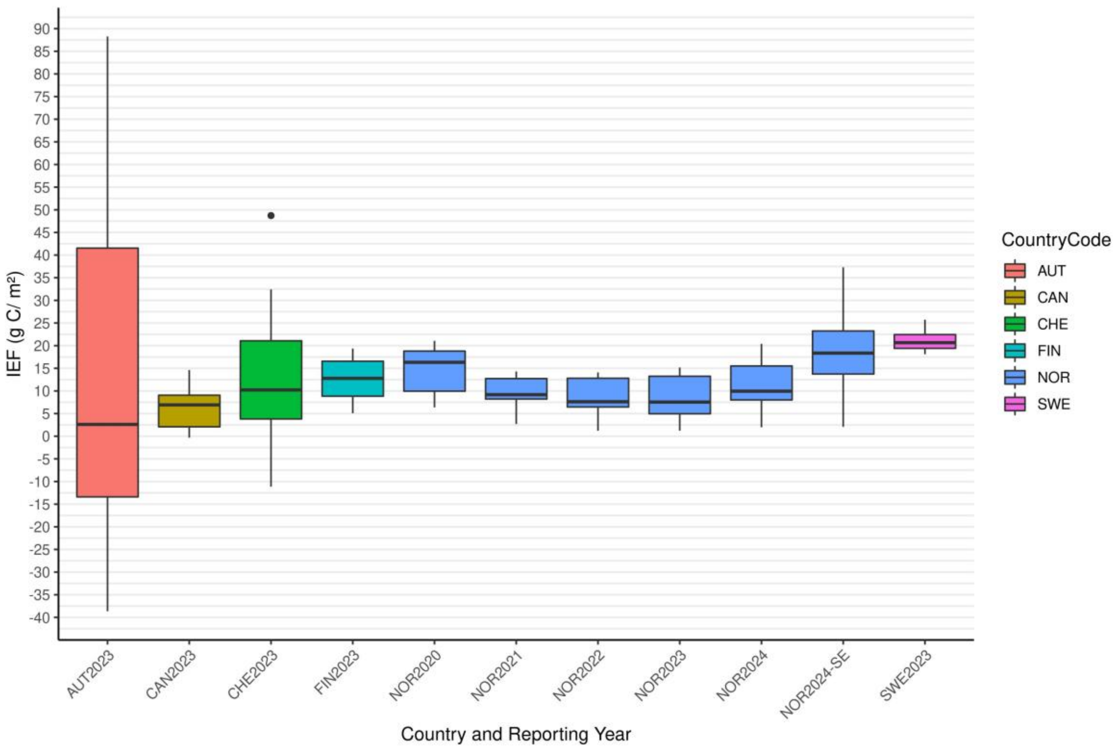


Figure 6.21: Boxplot of the sum of implied emission factors (IEF)50 for dead wood, litter and mineral soil for Forest land remaining Forest from CRF tables for the countries Austria (AUT), Canada (CAN), Switzerland (CHE), Finland (FIN), Sweden (SWE) and Norway (NOR). Except for Sweden and Canada, all countries presented use Yasso for dead wood, litter and mineral soil carbon stock change (CSC). Canada uses a carbon budget model, CBM-CFS3 (Kurz 2009), and 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,

[50] IEF from the CRF tables are not directly used in the figure for Norway. This is because CRF reporter calculates litter and dead wood IEF by dividing the reported CSC by the total area for forest land remaining forest land. However, Yasso07 is only run on land which is mineral soil. Henceforth, dead wood, litter, and mineral soil IEF presented for Norway have all be corrected by dividing the CSC with the mineral soil area.

2021, 2022, 2023, and 2024 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. In NOR2023 improved dynamic climate data ("x"-year backwards looking moving average, in which "x" refers to the length of the number of years for the time interval between each NFI plot observation. Initially the time interval varied from 1 to 12 years for each plot between the first and second measurement during the period 1986 to 1998, see section 6.3.4.1). In NOR2024 scripts were updated in which available temporal biomass estimates from natural morality and other harvest derived from NFI observations are used as input in the Yasso07 model, instead of biomass estimates calculated as a fraction of the standing biomass. NOR2024-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 span of Switzerland and Canada. South-eastern Norway is especially closer to estimates from Sweden. Austria seems to be the outlier and has relatively high annual variance compared with the other countries. 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 can produce 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 NOR2024-SE in Figure 6.21; (see details in Lange et al. (2017) and Kjønaas 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 6.22). 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^{2}yr):
    - At one site, "Nordmoen" (well drained podzol), Yasso07 estimated SOC stocks similar to measured stocks. Simulated changes (g C/m^{2}yr) averaged for the 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^{2}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^{2}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.

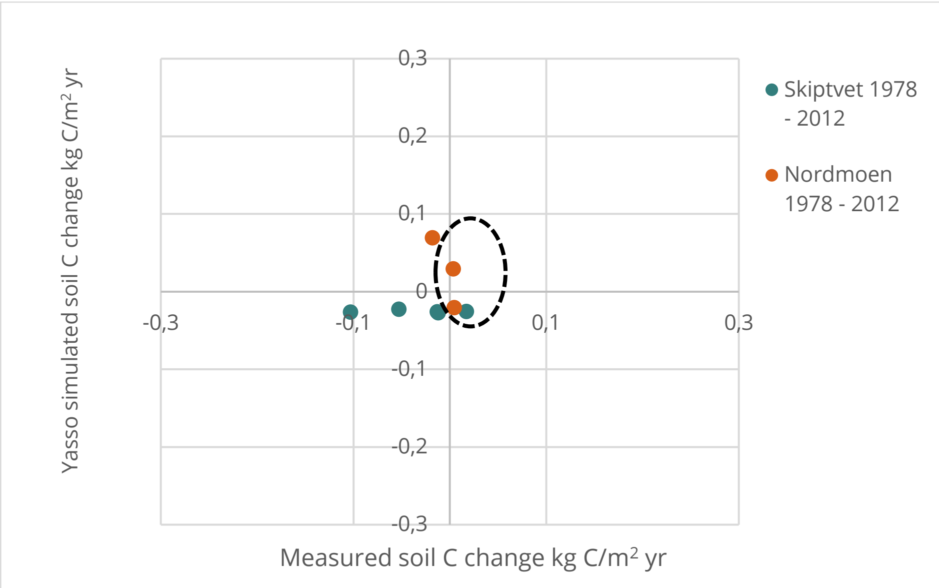


Figure 6.22: Mean annual changes 1978 -2012 for measured and simulated soil C. For the site "Skiptvet" the different point (treatments) are different mixtures of spruce and birch. For the site "Nordmoen" the treatments are monocultures of birch (highest simulated change), pine (intermedium simulated 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. (2017), Dalsgaard, Lise et al. (2016) 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 and 2023 soil data from four experimental forest sites with base-line SOC data from approximately 2011-2013 were collected. Targeted funding is secured for model evaluation on these four sites (in addition to the two sites where data is illustrated in Figure 6.22). The six sites (Figure 6.23) 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 of the six sites are found in the south-east, where also most of the forest is located.

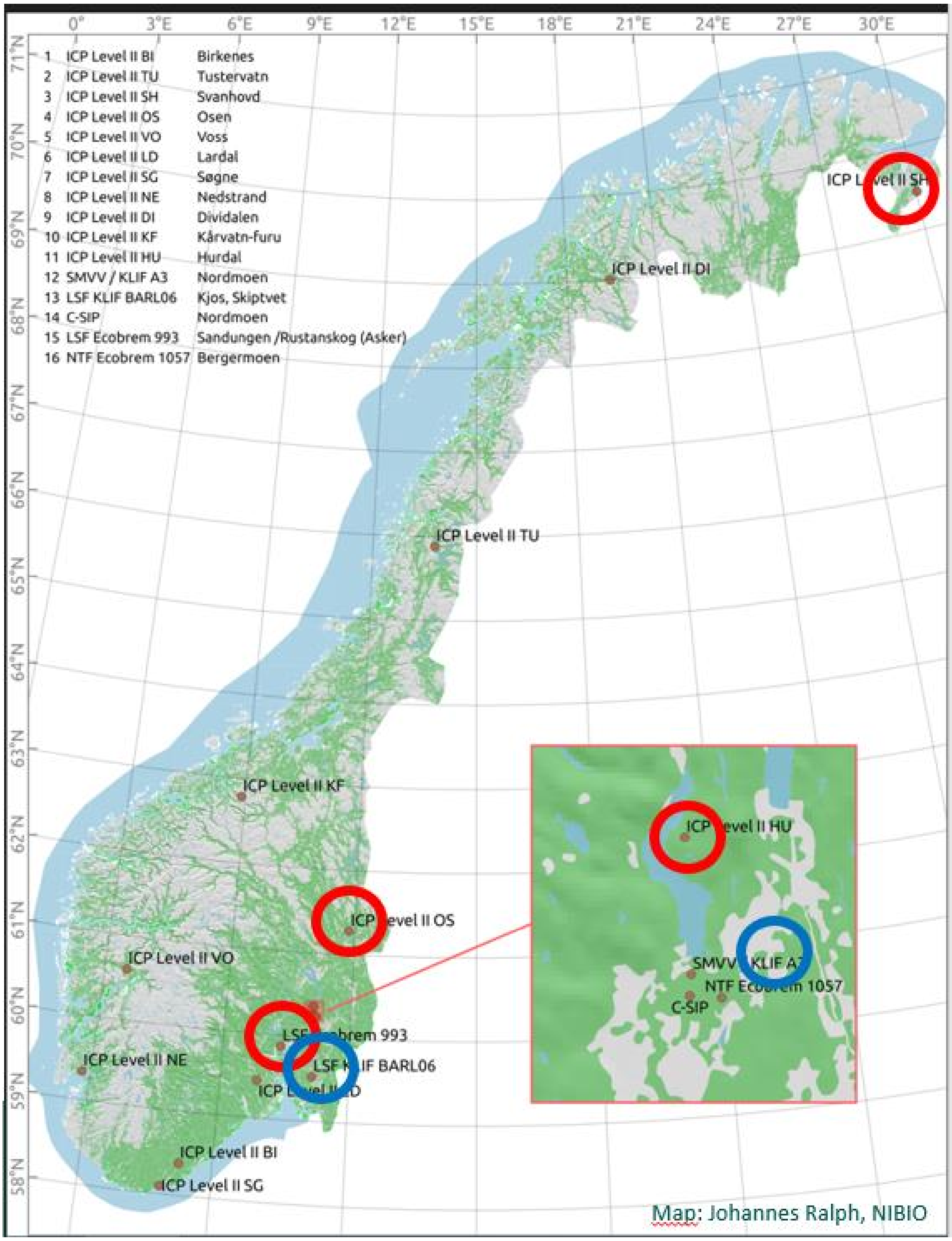


Figure 6.23: Experimental forest sites where base-line SOC from approximately 2010 is available and repeated soil sampling is relevant for site specific comparison of model and measured SOC change. Blue circles show the sites where SOC change was measured and simulated in 2017 (see above), and red circles show sites where SOC changes were measured in 2022/2023 but where comparison to simulated changes are not yet performed. The map is produced by NIBIO.

6.4.1.3 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 Annex 4.

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^2 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.

6.4.1.4 Recalculations

See chapter 10.2.4. for numbers and explanations.

6.4.1.5 Planned improvements

<u>Living biomass, dead organic matter, mineral soils, and drained organic soils.</u>
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, settlements, and unmanaged wetlands to forest land is identified as a key category. Details on identification criteria can be found in chapter 1.4.

<u>Choice of method, C stock change factors, and activity data</u>

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).

Conversions from grassland and cropland to forest land results in instant grass biomass losses in the first year of conversion (Table 6-20).

Table 6-20: Default biomass carbon stocks change factors for conversion to forest land.

Conversion	Biomass gain/losses (tC ha $^{-1}$)	Herbaceous biomass factor (tC (t d.m.)$^{-1}$)	IPCC Climate region	Reference
Grassland to forest land (biomass loss)	3.995	0.47	Boreal	IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4
	3.055		Cool temperate dry	
	6.392		Cool temperate moist	
Cropland to forest land (biomass loss	4.7		-	IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9

For tree living biomass, NFI data on individual trees are used. For grass and crop biomass, areas obtained through the NFI are used.

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 is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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://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^{-1} yr^{-1}) for land converted to forest land.

Ecological climate zones	Litter (tC ha^{-1} yr^{-1})		Dead wood (tC ha^{-1} yr^{-1})	
	deciduous	conifers	deciduous	conifers
Boreal Moist Coniferous Forest	1.05	2.1	0.82	1.11
Cool Temperate Moist Mountain System	0.3	0.4	1.06	2.405
Cool Temperate Oceanic Forest	0.3	0.35	1.84	1.84
Cool Temperate Continental Forest	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 several 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 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 $\Delta SOC = (SOC0 – SOC0\text{-}T)/D$ (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^{-1}), 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.

Table 6-22: Annual mineral soil carbon stock change rates (mean ± standard deviation in t C ha^{-1} yr^{-1}) for land converted to forest land (1990 – 2022).

IPCC climate region	Cropland	Intensive Grassland	Settlements
Cool Temperate Moist	0.659 ± 0.097	-0.0751 ± 0.0064	0.1 ± 0.25

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^{-1} 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 Annex 2.

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

See chapter 10.2.4. for numbers and explanations.

6.4.2.5 Planned improvements

<u>Living biomass, dead organic matter, mineral soils, and drained organic soils</u>

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 2022, 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. Throughout the time series, we initially observed a decrease in the total area of cropland. However, in the last decade, this trend has reversed with an increase, primarily due to conversions from forest land and, to a lesser extent, from wetlands in organic soils. CO_2 emissions from living biomass, DOM, mineral and organic soils on croplands are reported in CRF Table 4.B as described below, and CH_4 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, most 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_2 removals is observed for mineral soils.

6.5.1.1 Methodological issues

Annual changes in C stocks on cropland remaining cropland (C_{CC}) can be estimated as the sum of changes in living biomass (C_{LB}) and soils (C_{SO}) 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 practiced. 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 & Hylen 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 (ΔC_{LB}) is equal to the absolute C gain (ΔC_G) minus the absolute C loss (C_L) 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 2022 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, and the corresponding value for maximum above-ground biomass C stock at harvest (Table 6-23). 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 fruit tree area estimates provided by Statistics Norway. 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 and replaced with the age class of 1-year-old. If there is a net increase in area 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 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 t C ha^{-1}, 8.07 t C ha^{-1}, 7.64 t C ha^{-1}, etc.).

Table 6-23: Default maximum above-ground biomass and above ground biomass accumulation rate for perennial cropland monocultures.

Factor	Definition	Climate region	IPCC default
G	Above-ground biomass accumulation rate	Temperate	0.43 t C ha^{-1} yr^{-1}
Lmax	Maximum above-ground biomass C stock at harvest	Temperate	8.5 t C ha^{-1}

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 ≤ 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 Norwegian fruit 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 carbon removals, 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 $\Delta SOC = (SOC_0 - SOC_{0-T})/D$, where D is the time dependency of the stock change factors. SOC_0 is the stock in the last year of the inventory period, and 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*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 carbon removal, 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_2 emissions within the source categories for cropland. It was identified as a key category. Details on identification criteria can be found in chapter 1.4.

The Norwegian definition of organic soils for cropland is described in detail in section 6.2.3,

Table 6-8.

Choice of method and emission factor

A Tier 1 method is used for the estimation of CO_2 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_{LOSS} = A × 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_2 C ha^{-1} yr^{-1}.

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 for emissions estimations 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 Statistics Norway. 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 Statistics Norway, 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 default uncertainty error for aboveground woody biomass accumulation in the temperate climate follows the IPCC 2019 Refinement. Statistics Norway estimated the uncertainty of the activity data to be negligible. The areas of orchards are used directly from the Norwegian Agricultural Authority and Statistics Norway 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. Uncertainties for activity data, emission factors and total values are described in Annex 2.

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 in Annex 2. 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 and Statistics Norway. 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 based on expert judgment. For organic soils, the area uncertainty was estimated, and default uncertainties were used from the guidelines. Uncertainties for activity data, emission factors and total values are described in Annex 2.

6.5.1.3 QA/QC and verification

The standard Tier 1 QC procedures described in Annex 4 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

See chapter 10.2.4. for numbers and explanations.

6.5.1.5 Planned improvements

<u>Living biomass, dead organic matter, mineral soils, and organic soils</u>
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-reporter.

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. Details on identification criteria can be found in chapter 1.4.

<u>Choice of method, C stock change factors, and activity data</u>

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.

Conversions of grassland to cropland result in instant grass biomass losses 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. All other conversions of land to cropland result in instant annual crop biomass gains in the first year of conversion in accordance with default Tier 1 methodology in IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9. Details are provided below.

Table 6-24: Default biomass carbon stocks change factors for conversion to cropland.

<table>
<tr><th>Conversion</th><th>Biomass gain/losses (tC ha^{-1})</th><th>Herbaceous biomass factor (tC (t d.m.)$^{-1}$)</th><th>IPCC Climate region</th><th>Reference</th></tr>
<tr><td rowspan="3">Grassland to cropland (biomass loss)</td><td>3.995</td><td rowspan="3">0.47</td><td>Boreal</td><td rowspan="3">IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4</td></tr>
<tr><td>3.055</td><td>Cool temperate dry</td></tr>
<tr><td>6.392</td><td>Cool temperate moist</td></tr>
<tr><td>All lands to cropland (biomass gain)</td><td>4.7</td><td>0.47</td><td>-</td><td>IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9</td></tr>
</table>

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. Details on identification criteria can be found in chapter 1.4.

<u>Choice of method, C stock change factors, and activity data</u>

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 6-25 presents the DOM carbon stock loss factors for forest land converted to cropland currently found in Norway.

Table 6-25: Instant DOM carbon stock loss (t C ha^{-1}) for forest land converted to cropland.

Ecological climate zones	Litter (tC ha^{-1})		Dead wood (tC ha^{-1})	
	deciduous	conifers	deciduous	conifers
Cool Temperate Moist Mountain System	6	8	21.2	48.1
Cool Temperate Oceanic Forest	6	7	36.8	36.8
Cool Temperate Continental Forest	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 (key category)

Mineral soils on forest land converted to cropland was identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 – 2022 for lands converted to cropland can be found in Table 6-26.

Table 6-26: Annual mineral soil carbon stock change rates (mean ± standard deviation in t C ha^{-1} yr^{-1}) for lands converted to cropland (1990 – 2022).

IPCC climate region	Forest land	Extensive Grassland	Intensive Grassland	Settlements
Cool Temperate Moist	-0.706 ± 0.099	-0.787	-0.661 ± 0.071	-0.25 ± 0.14

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 unmanaged wetlands converted to cropland on organic soils are identified as key categories. Details on identification criteria can be found in chapter 1.4.

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 t C ha^{-1} yr^{-1} was applied, assuming similar emissions as for cropland remaining cropland, regardless of the previous land use.

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 Annex 2 and shown as total aggregated uncertainty (U_{total}) based on the uncertainties of the C stock change (CSC) and the area estimates for living biomass, DOM, mineral and organic soils.

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

See chapter 10.2.4. for numbers and explanations.

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 6-27):

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 ≥ 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 (Lyngheilandskapet) 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 6-27: Identified Grassland types.

Grassland type	Grassland area (2015 – 2019)	Mechanically ploughable	Mechanically harvestable	Area enclosed	Shrubland
Intensive grassland					
Closed pastures	1.8%	No	No	Yes	No
No-till cultivated grass pastures	0.2%	No	Yes	-	No
Extensive grassland					
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 removals in forest land remaining forest land. From 1990 ‑ 2021, the cumulative sum of net living biomass sequestrated on forested grassland remaining forested grassland plots is approximately 0.2% (325 kt C) of the net living biomass removals in forest land remaining forest land. There is currently not enough empirical data or scientific literature to adequately describe the entire 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.

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 and extensive grassland remaining extensive grassland is identified as a key category. Details on identification criteria can be found in chapter 1.4.

Choice of method

Living biomass on grassland has been measured in the NFI since 2007. Some plots, however, have been reclassified from forest to extensive grassland over the years, and measurements have been taken for those plots for the whole time series. For plots that had always been extensive grassland and therefore only measured from 2007 onwards, gains and losses were backcasted to complete the time series. In this case, a Tier 3 methodology was used, similar to that used for forest remaining forest.

The same approach is not feasible for intensive grasslands, given the diverse management practices the areas have undergone over the years. In these cases, the average CSC (gains and losses) per hectare and year was calculated based on sample plots remeasured between 2012 to 2016. The average C gain and loss were then multiplied by the area of intensive grassland remaining intensive grassland for the years 1990 – 2011 to obtain total estimates (which represents a Tier 2 methodology). For 2012 onwards, actual NFI measurements (Tier 3) were used. In alignment with the guidelines on time series consistency as provided in IPCC 2019 Refinement v.01, chapter 5, splicing techniques such as surrogate data, were examined. Yet, the significant variability in management practices across intensive grasslands made auxiliary data unsuitable for addressing the existing gap. The decision to employ two different Tiers within the same time series is with the intent to " *...optimally utilize the most accurate emission parameters and other data collected within the relevant contexts*" as emphasized in the IPCC 2019 Refinement.

6.6.1.1.2 Mineral soils (key category)

Mineral soil on intensive grassland remaining intensive grassland is identified as a key category. Details on identification criteria can be found in chapter 1.4.

Choice of method

For intensive grasslands, a default Tier 1 approach was used for estimating CO_2 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_0) and the beginning (SOC_{0-T}) of the inventory period (T) divided by the time dependency of the stock change factors (D = 20 years) and is given by

$$\Delta SOC = (SOC_0 - SOC_{0-T})/D \qquad \text{Equation 2.25 (IPCC 2006).}$$

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_{0-T} is calculated for 1989 based on the assumption that SOC was at equilibrium before 1990.

$$\Delta SOC = \frac{SOC_0\,(year = current\ year) - SOC_{0-T}(year = 1989)}{20\ years}$$

From 2010 onward, the year for estimating $SOC_{0\text{-}T}$ increased from 1990 by one year every new year.

$$\Delta SOC = \frac{SOC_0\,(year = current\ year) - SOC_{0-T}(year = current\ year - 20)}{20\ years}$$

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

$SOC = SOC_{REF} \times SCF \times A$ 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.

For mineral soil on grassland remaining grassland, carbon stock change (CSC) only occurs when a management change occurs. In the case of Norwegian grasslands, we introduced a few management change limitations which impacted the CSC calculation. These changes and their consequences, include (1) management transition between no-till cultivated pastures and all extensive grassland are unlikely to happen, (2) management transition between No-till cultivated and closed pastures can happen, (3) management transition between extensive grassland and closed pastures can happen.

For example, a land with a good grass yield, could be converted to a closed pasture, but would unlikely be abandoned. And conversely, an open pasture could be fenced but may not be good enough for cultivation. Therefore, all transitions between intensive and extensive grasslands occurs between the closed pastures and the extensive grasslands categories. Because these grassland categories share the same combination of partial stock change factors (see Table 6-29), they do not incur any carbon stock change (i.e. CSC=0). Similarly, management change within the extensive grassland categories sharing the same SCF result in null CSC. Therefore, non-neutral CSC are only generated by transitions within intensive grasslands, between no-till cultivated and closed pastures. 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 6.3.3 and Bárcena et al. (2021).

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 Statistics Norway (Table 6-28). Statistics Norway 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 6-28: Areas (kha) of grassland remaining grassland on mineral soils in Norway from 1990 to 2022 from two different sources (NFI and Statistics Norway).

Year	Statistics Norway (SSB)			NFI database	
	Intensive Grassland			Intensive Grassland	Extensive Grassland
	Closed pastures	No-till cultivated pastures	Total		
1990	81	27	109	226	11301
1991	85	27	112	225	11301
1992	90	27	117	225	11300
1993	94	26	120	224	11299
1994	98	26	124	223	11299
1995	101	26	127	222	11298
1996	103	27	130	221	11298
1997	108	25	133	220	11297
1998	111	29	141	219	11297
1999	122	30	151	218	11296
2000	129	29	158	217	11296
2001	132	28	161	216	11295
2002	135	28	163	215	11295

2003	137	27	164	215	11294
2004	139	27	166	214	11293
2005	142	27	169	214	11292
2006	146	26	172	213	11292
2007	149	25	175	212	11291
2008	151	24	175	210	11289
2009	152	22	175	209	11288
2010	155	21	176	207	11286
2011	156	20	177	206	11282
2012	156	20	177	205	11278
2013	156	20	176	204	11274
2014	156	20	176	203	11270
2015	156	20	176	203	11266
2016	156	20	176	203	11263
2017	161	20	181	204	11260
2018	159	20	179	204	11256
2019	159	20	179	205	11252
2020	158	21	178	205	11249
2021	156	21	177	205	11245
2022	156	21	177	205	11241

The intensive grassland areas per management type were stratified into eight regions (Figure 6.24). The area data from Statistics Norway (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.

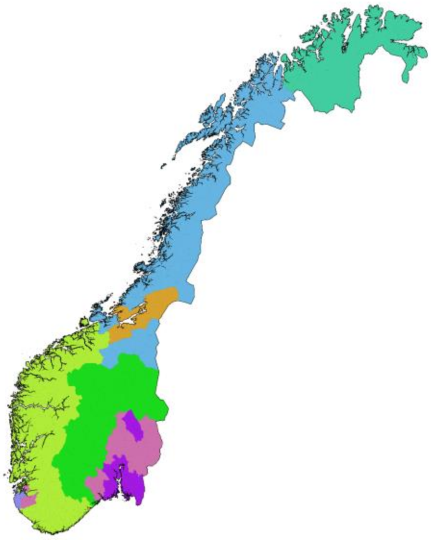


Figure 6.24: Eight regions of Norway were used to stratify grassland activity data for the Tier 1 application.

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} x F_{MG} x 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 the table below.

Table 6-29: Relative Carbon Stock Change factors (SCF) for grassland in a temperate/boreal climate regime.

Factor	Level	IPCC default	Definition
F_{LU}	All	1.00	All grasslands
F_{MG}	Non-degraded	1.00	Non-degraded, 0 improvements*
	Moderately degraded	0.95	Moderately degraded, reduced loss of productivity overgrazed, 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, 0 improvement*

	Improved	1.14	Non-degraded, moderate grazing pressure, 1 improvement*
F_I	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_{LU}, F_{MG}, and F_I combination for each intensive grassland category. For the land-use factor F_{LU}, the situation is simple as it is fixed to (F_{LU} = 1) for all types of intensive grassland. Determining the factors for management F_{MG} and organic matter input F_I 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 6-29). Then, it depends on the general degradation of the intensive grassland category due to grazing pressure.

As grassland irrigation is generally not practiced 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^2 would induce no change in the soil organic carbon storage (~ 5% increase). In contrast, a sheep density of 80 animal km^2 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^2, which is below the animal density that would induce a SOC loss (https://kilden.nibio.no).

Table 6-30: Distribution of domestic grazing animals† density in Norwegian pastures (2018).

Density (head/km^2)	Grassland areas (%)
0-25	84.0
26-50	13.7
51-75	1.7
>75	0.6

†: 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 6-30). 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^2 (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).

<u>Soil Carbon Reference values</u>
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 (WRB 2015) 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 6.25).

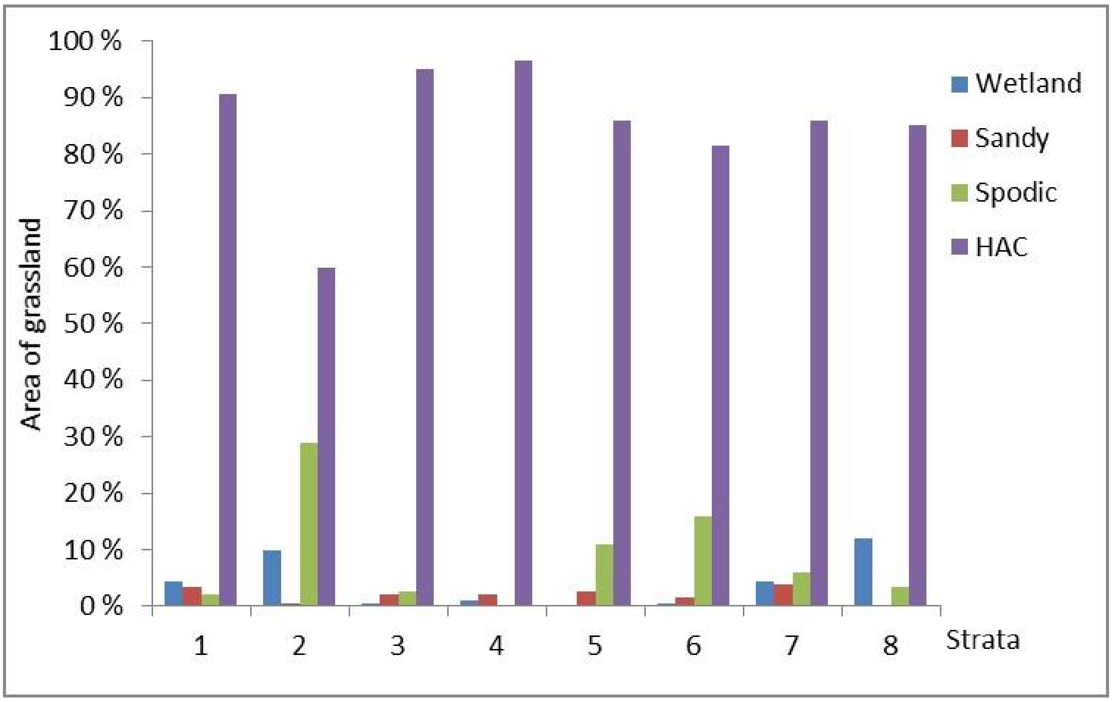


Figure 6.25: Distribution of soil types in intensive grassland areas for the eight strata. The IPCC soil types are high-activity clay soils (HAC): leptosols, fluvisol, phaeosem, albeluvisol, luvisol, umbrisol, cambisol, regosol; wetland soils: gleysols; sandy soils: arenosols; and spodic soils: podzol.

The soil C reference stock (SOC_{REF}) values are shown in Table 6-31. 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.

Table 6-31: Soil carbon reference stock (SOC_{REF}) for different classes of soils.

Grassland type	SOC_{REF} (t C ha^{-1})	Climate zone	Reference
HAC	95	Cold temperate moist	IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.3
Sandy	71		
Spodic	115		
Wetland	87		

6.6.1.1.3 Organic soils (key category)

Organic soil on intensive grassland remaining intensive grassland is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 t C ha^{-1} yr^{-1} was applied (IPCC 2014). 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 Annex 2.

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. The default C reference stock is provided in 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 (Statistics Norway 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 Statistics Norway. 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. 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 6.1.4. The total uncertainty for the mineral soil estimate was propagated using Equation 3.1 of 2006 IPCC Guidelines, Vol.1, Ch. 3. 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 Annex 2.

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

See chapter 10.2.4. for numbers and explanations.

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, cropland, 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 cropland and 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.

6.6.2.1 Methodological issues

6.6.2.1.1 Living biomass (key category)

The sink/source category living biomass on forest land converted to intensive grasslands is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 in the first year of conversion, as shown in Table 6-32.

Table 6-32: Default biomass carbon stocks change factors for conversion to grassland.

Conversion	Biomass gain/losses (tC ha^{-1})	Herbaceous biomass factor (tC (t d.m.)$^{-1}$)	IPCC Climate region	Reference
All lands to grassland (biomass gain)	3.995	0.47	Boreal	IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4
	3.055		Cool temperate dry	
	6.392		Cool temperate moist	

6.6.2.1.2 Dead organic matter (key category)

The sink/source category dead organic matter on forest land converted to intensive grasslands is identified as a key category. Details on identification criteria can be found in chapter 1.4.

<u>Method choice, C stock change factors, and activity data</u>

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 6-33 presents the DOM carbon stock loss factors for forest land converted to grassland currently found in Norway.

Table 6-33: Instant DOM carbon stock loss factor (t C ha^{-1}) for forest land converted to grassland.

Ecological climate zones	Litter (tC ha^{-1})		Dead wood (tC ha^{-1})	
	deciduous	conifers	deciduous	conifers
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 can be found in Table 6-34.

Table 6-34: Annual mineral soil carbon stock change rates (mean ± standard deviation in t C ha-1 yr-1) for lands converted to grassland.

Grassland subcategory	IPCC climate region	Forest land	Settlements
Intensive	Cool Temperate Dry	0.02	
	Cool Temperate Moist	0.0764 ± 0.0065	0.47 ± 0.42

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 t C ha^{-1} 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 Annex 2. 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

See chapter 10.2.4. for numbers and explanations.

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 considered at equilibrium for managed or unmanaged wetlands. Emissions from drained organic soil for peat extraction and mires with ditches (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
CSC in DOM on waterbodies do not occur, and so are reported as NO. CSC in DOM on peat soil (organic soil) are considered at equilibrium and therefore reported as NO in accordance with Tier 1 methodology 2013 Wetlands supplement.

6.7.1.1.3 Mineral soil
CSC in mineral soils is reported as NO.

6.7.1.1.4 Peat extraction (managed wetlands) - Organic soil (key category)
The source category peat extraction on organic soil is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 2014). 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; IPCC 2014).

The area utilized for peat extraction is estimated to be 2 kha for the entire time series. On-site emissions caused by peat extraction are thus constant over the inventory period. Off-site emissions vary over the years. Emissions from peat extraction (on-site + off-site) are shown in Table 6-35.

Table 6-35: On-site and off-site emissions for peat extraction for the latest reporting year.

Parameter	Gas	On-site (constant) kt	Off-site (vary) kt	Total kt
Emissions	CO_2	20.5	61.0	81.5
	N_2O	0.0009	-	0.0009
	CH_4	0.0658	-	0.0658
	Total CO_2 Eq	22.6	61.0	83.6

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_2 emissions are estimated using a national emission factor based on expert judgement, and it is a Tier 2 method.

Table 6-36: 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%
On-site				
CO_2	2.8 t CO_2 C ha^{-1} yr^{-1}	50	100	110
$CH_{4\ LAND}$	6.1 kg CH_4 $ha^{-1}yr^{-1}$	80	100	128
$CH_{4\ DITCH}$	542 kg CH_4 ha^{-1} yr^{-1}	81	100	129
$Frac_{ditch}$	0.05			
N_2O	0.30 kg N_2O-N $ha^{-1}yr^{-1}$	113	100	151
Off-site				
CO_2	0.05 t C m^{-3} air-dry peat*	50	50	71

** Peat dry matter density of 0.1 t m^{-3} and a C content of 50%.*

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), in 2021 (covering the years 2015-2021), and in 2023 (covering the years 2022 and 2023). 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 Søgaard (2017).

6.7.1.1.5 Mires with ditches (managed wetlands) – Organic soil (key category)

The source category mires with ditches on organic soil is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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.

<u>Choice of method, activity data, and emission factor</u>

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_2 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_2 yr^{-1} ha^{-1}, as it represents the most up-to-date information.

6.7.1.1.6 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_2 emission uncertainties were combined by the weighted sum of the variances (square of total uncertainty % in

Table 6-36), 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_4 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. Uncertainties for CO_2, CH_4 and N_2O emissions estimated from drained organic soils on wetlands used for peat extraction are shown in Annex 2.

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_2 emission factor (Søgaard 2017).

6.7.1.4 Recalculations

See chapter 10.2.4. for numbers and explanations.

6.7.1.5 Planned improvements

<u>Living biomass, dead organic matter, mineral soils, peat extraction, mires with ditches and unmanaged wetlands</u>

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 organic 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.

6.7.2.2 Living biomass

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 in the first year of conversion, as shown in Table 6-37.

Table 6-37: Default biomass carbon stocks change factors for conversion to wetlands.

Conversion	Biomass gain/losses ($tC\ ha^{-1}$)	Herbaceous biomass factor ($tC\ (t\ d.m.)^{-1}$)	IPCC Climate region	Reference
Grassland to wetlands (biomass loss)	3.995	0.47	Boreal	IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4
	3.055		Cool temperate dry	
	6.392		Cool temperate moist	

6.7.2.2.1 Dead organic matter (key category)

The source category dead organic matter on forest land converted to managed wetlands is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 6-38 presents the DOM carbon stock loss factors for forest land converted to wetlands in Norway.

Table 6-38: Instant DOM carbon stock loss ($t\ C\ ha^{-1}$) for forest land converted to wetlands.

Ecological climate zones	Litter ($tC\ ha^{-1}$)		Litter ($tC\ ha^{-1}$)	
	deciduous	conifers	deciduous	conifers
Cool Temperate Continental Forest	27	70	23.6	22.1

6.7.2.2.2 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.

6.7.2.2.3 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^{-1} yr^{-1} (IPCC 2014). The conversion of extensive grasslands to wetlands on organic soil cannot occur, and the notation key NO is therefore reported in the CRF.

6.7.2.3 QA/QC and verification

The standard Tier 1 QA/QC procedures were performed.

6.7.2.4 Recalculations

See chapter 10.2.4. for numbers and explanations.

6.7.2.5 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_2, CH_4, and N_2O emissions from lands converted to peat extraction are reported as NE. Norway reports emissions for Lands Remaining Peatland Extraction but not for Lands converted to Peatland Extraction. An assessment was made of the likely level of emissions from lands converted to peat 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.

To evaluate this emission as “non-significant”, it was related to the Norwegian emissions from all sectors except the LULUCF sector, as explained in chapter 1.7.

Box 3 - Peat extraction

To gather information about peat extraction, three surveys have been conducted. In 2015, 2021 and 2023. 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. The producers where not asked about the area they use in 2023. Based on the results from the two first 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: Lands converted for peat extraction (ha) = total area (694 ha)/number of years (31 years) * 20 years = 447.7 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^3/ha) was calculated for each year. Then the peat extracted from land converted for peat extraction was calculated for each year: Peat extracted on land converted for peat extraction = Peat (m^3)/ha * 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.

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 6-39).

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 6-39: Total greenspace percentage. That is the proportion of land area covered by vegetation or open soil used for the Tier 1 methodology.

NFI range in % total greenspace	Total greenspace% as applied for the calculations in the GHG inventory (Tier1)
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 6-40). Turfgrass and Vegetated on mineral soil wooded areas were stratified into a fifth category

(5) “wooded” (with trees). Figure 6.26 shows the area distribution of each category within the settlements land use.

Table 6-40: Settlements subdivision classes.

Classes	Definition
Infrastructure (I)	Soil is totally removed in most cases (e.g. motorways, houses, and other buildings).[1]
Paved (P)	Soil is paved over (e.g. forest roads, sidewalks)[1]
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.

[1] 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.

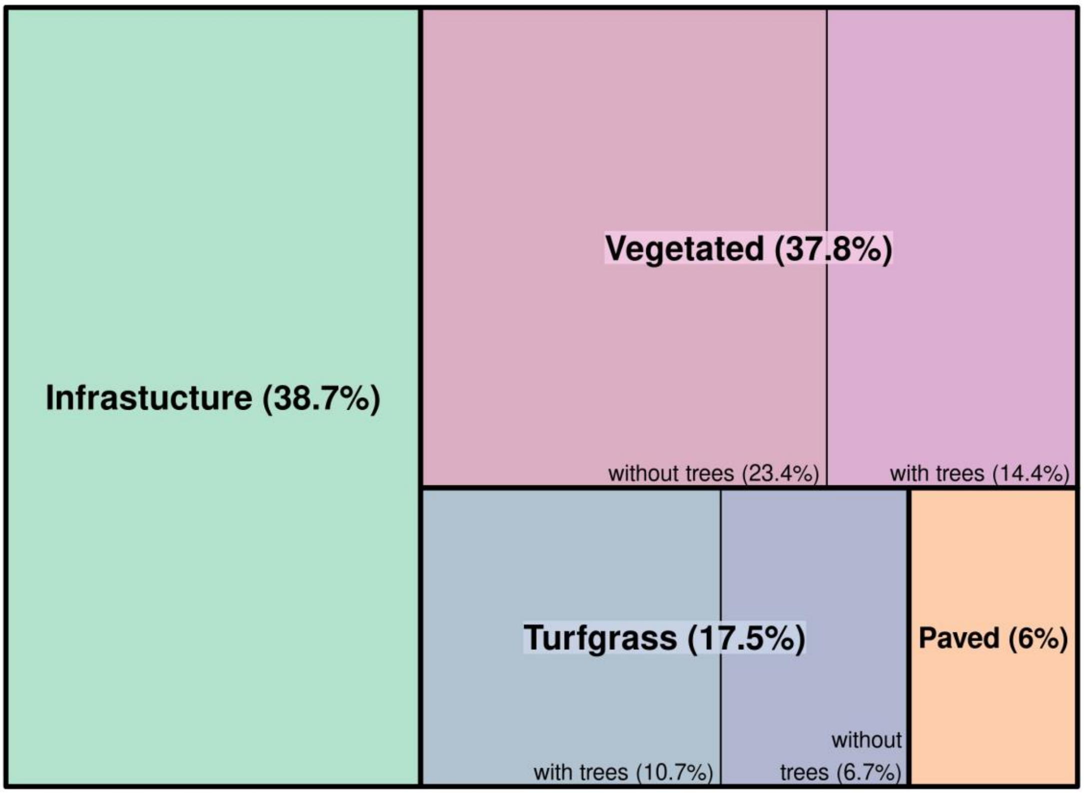


Figure 6.26: Settlement subcategory area distribution (2018-2022).

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.

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 a marginal portion of the Norwegian land area and hold a negligible fraction 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. Details on identification criteria can be found in chapter 1.4.

Norway utilizes the Tier 1 methodology (IPCC 2006; IPCC 2014) to estimate CO_2 emissions from settlements remaining settlements on drained organic soils. The Tier 1 method utilizes Equation 2.26 $L_{Organic} = \sum(A \cdot EF)_c$, where $L_{Organic}$ = annual carbon loss from drained organic soils (tonnes C yr^{-1}), A = land area of drained organic soils in climate type *c* (ha), and EF = emission factor for climate type *c* (tonnes C $ha^{-1}yr^{-1}$) (IPCC 2014). The differing subdivision classes on settlements necessitate different EFs applied to the area of drained organic soil on settlements.

According to IPCC (2014), 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 2014) default EFs to the different subdivision classes as described in Table 6-41.

Table 6-41: Settlements subdivision classes and their associated Tier 1 EF's on organic soils. EF for CO_2 (tC ha^{-1} yr^{-1}) is from Table 2.1 in the IPCC 2013 Wetlands supplement.

Classes	CO_2 (tC $ha^{-1}yr^{-1}$)	IPCC land use catagory[1]
Temperate climate zone		
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
Boreal climate zone		
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 Annex 2.

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

See chapter 10.2.4. for numbers and explanations.

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 conversions from forest land.

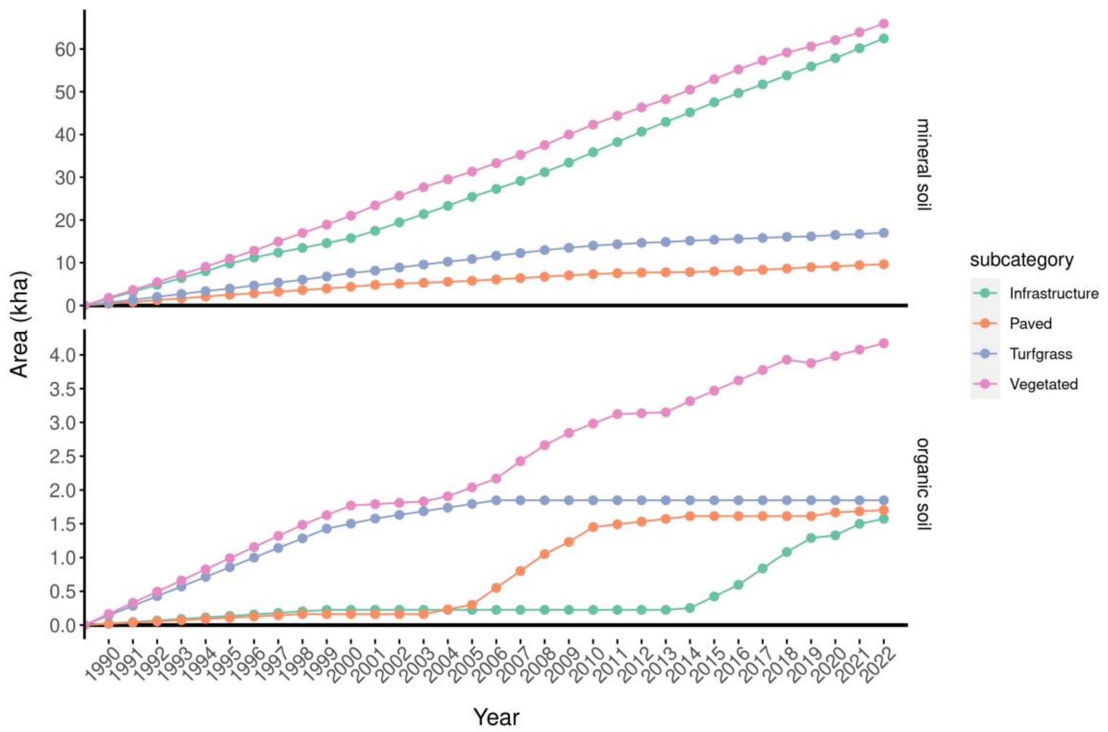


Figure 6.27: Cumulative land-use change area to settlement subcategories (excluding 20-year transition rule to remaining category).

6.8.2.1 Methodological issues

6.8.2.1.1 Living biomass (key category)

The source category living biomass on forest land converted to settlements is identified as a key category. Details on identification criteria can be found in chapter 1.4.

Woody biomass

For forest land and wetlands[51] 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 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 3/2 method is applied. Sample plots converted from grassland to settlements prior 2007 did not have tree living biomass.

No woody biomass losses or gains are reported for conversions from croplands and other lands to settlements.

Non-woody biomass

Conversions from grassland to non-greenspace settlements results in instant grass biomass losses in the first year of conversion. Conversions from cropland to all settlements results in instant annual crop biomass losses in the first year of conversion. All land-use conversions, excluding grasslands, to greenspace settlements results in instant grass biomass gains in the first year of conversion. See overview of factors in Table 6-42.

[51] With at least 5% crown cover. At the latest since 2007, trees are measured independent of crown cover.

Table 6-42: Default biomass carbon stocks change factors for conversion to settlements.

Conversion	Biomass gain/losses (tC ha^{-1})	Herbaceous biomass factor (tC (t d.m.)$^{-1}$)	IPCC Climate region	Reference
Grassland to non-greenspace settlements (biomass loss) & Lands converted (excl. grasslands) to greenspace settlements (biomass gains)	3.995	0.47	Boreal	IPCC 2006 Guidelines, Vol. 4, Ch. 6, Table 6.4
	3.055		Cool temperate dry	
	6.392		Cool temperate moist	
Cropland to settlements (biomass loss)	4.7		-	IPCC 2019 Refinement, Vol. 4, Ch. 5, Table 5.9

6.8.2.1.2 Dead organic matter (key category)

The source category dead organic matter on forest land converted to settlements is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 6-43 presents the DOM carbon stock loss for forest land converted to settlements in Norway.

Table 6-43: Instant DOM carbon stock loss (t C ha^{-1}) for forest land converted to settlements.

Ecological climate zones	Litter (tC ha^{-1})		Dead wood (tC ha^{-1})	
	deciduous	conifers	deciduous	conifers
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 forest land and cropland converted to settlements is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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 = $F_{LU} \bullet F_{MG} \bullet F_I$) (Table 6-44). 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 6-44).

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 6-44: 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 6-45.

Table 6-45: Annual mineral soil carbon stock change rates (mean ± standard deviation in t C ha^{-1} yr^{-1}) for lands converted to settlements.

IPCC climate region	Cropland	Forest land	Intensive Grassland	Extensive Grassland	Unmanaged Wetlands (waterbody)
Boreal Dry		-0.661			
Cool Temperate Dry		-0.03 ± 0.029			
Cool Temperate Moist	0.52 ± 0.74	-0.39 ± 0.41	-0.331 ± 0.6	-0.44 ± 0.45	-0.218 ± 0.2

6.8.2.1.4 Organic soil (key category)

The source category organic soil on forest land and unmanaged wetlands converted to settlements is identified as a key category. Details on identification criteria can be found in chapter 1.4.

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_2. We apply different factors for instant oxidation (Table 6-46) according to soil depth classes (IPCC 2014). 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 carbon loss (Table 6-46).

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 6-46.

Table 6-46: Settlements subdivision classes and their associated Tier 1 EF's on organic soils. EF for CO_2 (tC ha^{-1} yr^{-1}) is from Table 2.1 in IPCC (2014).

Classes	C (t $ha^{-1}yr^{-1}$)	IPCC land use catagory[2]
Infrastructure (I)[1]		
Shallow (0.4 – 1 m)[3]	321.3	
Deep (> 1 m)[3]	918.0	

Temperate climate zone		
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
Boreal climate zone		
Paved (P)	5.7	Grassland, drained
Turfgrass (T)	5.7	Grassland, drained
Vegetated (V)	5.7	Grassland, drained

[1]These emissions are from instant oxidation and are only applied once for the initial transition.
[2]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.
[3]Based on a carbon density of 45.9 kg C/m^2 and an average depth of 0.7 m for shallow bogs and 2.0 m for deep bogs.

6.8.2.2 Uncertainties and time-series consistency

Uncertainties are shown in Annex 2 for living biomass, DOM, 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

See chapter 10.2.4. for numbers and explanations.

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 10% 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 2024. 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 2024, 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 6.1.4.

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. Details on identification criteria can be found in chapter 1.4.

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_2 in the base year 1990.

Net annual removals from HWP in use in 2022 were -183 kt CO_2 for HWP produced and consumed domestically, and -331 kt CO_2 for HWP produced and exported. In 2022, the total removals from the HWP pool were -514 kt CO_2.

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 2018, 2019, 2020, 2021 and 2022, the total of HWP categories again provided removals: sawnwood -597 kt CO_2 (-502 in 2021, -491 in 2020, -515 in 2019, -508 in 2018), wood-based panels -30 kt CO_2 (10 in 2021, 44 in 2020, 12 in 2019, 22 in 2018), paper and paperboard 113 kt CO_2 (196 in 2021, -4 in 2020, 29 in 2019, 104 in 2018). Hence, the main contribution to total HWP removals was from sawnwood, while the total HWP emissions were from paper and paperboard.

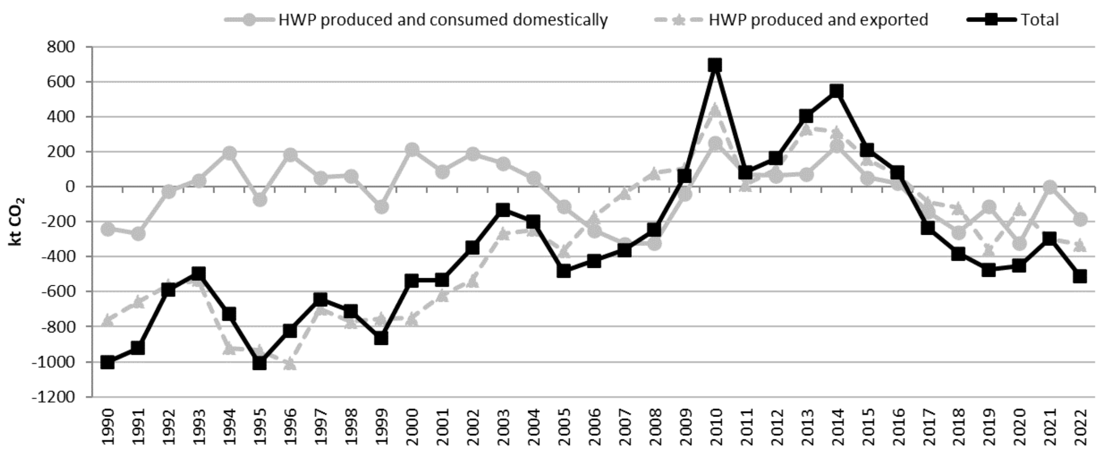


Figure 6.28: CO_2 emissions and removals in HWP (kt CO_2). Source: Norwegian Institute of Bioeconomy Research.

6.10.1 Methodological issues

6.10.1.1 Choice of method

Emissions and removals reported for HWP are estimated using a Tier 1 method from 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019). The calculations are based on chapter 12.4.2. The Tier 1 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 2019).

To improve transparency and in accordance with the guidelines (IPCC 2019) 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 2022. We calculated the historic pool from 1950 – 1960 according to IPCC (2019). Only emissions from 1990 and onwards are reported.

The estimation of C stocks (C) and annual carbon stock changes (ΔC) for each HWP category was estimated using Equation 12.2 (IPCC 2019)

$$C\ (i+1) = e^{-k}\ \times C(i) + \left[\frac{(1-e^{-k})}{k}\right] \times Inflow(i)$$

$$\Delta C\ (i) = C\ (i+1) - C\ (i)$$

where i = year; C (i) = the carbon stock (kt C) in the particular HWP category at the beginning of year i, with i = (1961,...,2022), but only emission estimates for i = (1990,...,2022) 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 yr^{-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; ΔC (i) = carbon stock change of the HWP category during year i, kt C yr^{-1}.

The approximation of the carbon stocks in HWP pools at initial time C ($i = t_0$ = 1961) was calculated according to Equation 12.4 (IPCC 2019)

$$C_{(t0)} = \frac{Inflow_{average}}{k}$$

where

$$Inflow_{average} = \frac{(\sum_{i=to}^{t4} Inflow\ (i))}{5}$$

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[52]. The initial unit is 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 (2019) . 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 1 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 2019).

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 ± 50%, according to IPCC (2006). In addition, there is 15% uncertainty related to the activity data – production and trade for countries with systematic census or surveys (IPCC 2006).

[52] http://www.fao.org/faostat/en/#data/FO

6.10.3 QA/QC and verification

The QA/QC plan was performed according to the Tier 1 procedure.

6.10.4 Recalculations

See chapter 10.2.4. for numbers and explanations.

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_2O emissions from managed soils – 4(I)

Direct N_2O 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 following the IPCC (2019). 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_2O 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_2O 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 started as a modest size in 1990, with both the area and the net quantity of N applied experiencing a decrease during the inventory period. However, in the years following 2015, the fertilized areas saw an increase due to the implementation of a new subsidy scheme. In 2022, however, the amount of fertilizer applied to forests reduced significantly, as a result of the price increase (

Table 6-47).

Table 6-47: Estimated emissions from fertilization of forest land.

Year	Fertilizer input (t N)		Net amount N applied (t N)	N_2O emissions (t N_2O)
	Mineral soil	Organic soil		
1990	201.1	83.2	284.3	7.1
1991	369.9	93.9	463.8	11.6
1992	287.8	144.5	432.3	10.8
1993	205.5	93.9	299.4	7.5
1994	191.9	93.9	285.7	7.1
1995	199.7	69.0	268.7	6.7
1996	262.4	60.1	322.5	8.0
1997	276.7	41.4	318.1	7.9
1998	293.9	48.3	342.1	8.5
1999	264.3	62.0	326.4	8.1
2000	197.9	30.6	228.5	5.7
2001	172.0	27.9	199.9	5.0
2002	191.6	12.3	203.9	5.1
2003	87.1	1.6	88.7	2.2
2004	96.1	4.1	100.3	2.5
2005	76.9	33.3	110.2	2.7
2006	52.9	8.3	61.2	1.5
2007	89.7	2.5	92.2	2.3
2008	111.7	2.5	114.1	2.8
2009	116.2	1.3	117.6	2.9
2010	85.0	0.5	85.5	2.1
2011	86.5	0.2	86.7	2.2
2012	125.4	0.4	125.8	3.1
2013	176.7	1.7	178.4	4.5
2014	74.1	0.0	74.1	1.8
2015	104.9	0.0	104.9	2.6
2016	1241.8	1.4	1243.2	30.9
2017	1344.8	4.0	1348.8	33.6
2018	838.8	0.0	838.8	20.9
2019	557.8	0.0	557.8	13.9
2020	648.2	0.0	648.2	16.2
2021	663.1	0.0	663.1	16.6
2022	46.3	0.0	46.3	1.2

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

$$N_2O\ direct\text{-}N_{fertlizer} = F_{SN} \times EF \times 44/28$$

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 on mineral and organic soils from 1990 to 1996. During this period, the amount of fertilizer used was computed using the average weight applied per hectare by helicopter. The nitrogen content depends on the type of fertilizer, supplied by Yara, which provided 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 percentage).

From 1997 onwards, we gathered fertilization data from Norway (2022) for each county. We then calculated the average proportion of fertilizer applied per county from 1997 to 2022. This data was used to retrospectively estimate the distribution of the total fertilizer amount for the earlier years (1990 to 1996). Once the data was split by county for the whole time series, we used the percentage of wet and dry climate within each county to apply the disaggregated emission factors, as recommended in the IPCC 2019 Refinement Vol. 4, Ch. 11, table 11.1.

6.11.1.1.3 Emission factor

The disaggregated emission factors used are shown in Table 6-48.

Table 6-48: Emission factors to estimate direct N_2O emissions from forest fertilization.

Factor	Disaggregation	Default value	IPCC default
EF_1	Synthetic fertiliser inputs in wet climates	0.016	IPCC 2019 Refinement, Vol. 4, Ch. 11, table 11.1
	All N inputs in dry climates	0.005	IPCC 2019 Refinement, Vol. 4, Ch. 11, table 11.1

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_2O 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 0.001 kt N_2O yr^{-1} in 1990 to 0.014 kt N_2O yr^{-1} in 2022 (0.26 to 3.8 kt CO_2 eq yr^{-1}).

6.11.3.1 Methodological issues

6.11.3.1.1 Choice of method

A Tier 1 method was used, applying the default emission factors disaggregated by wet and dry climate following the IPCC (2019).

6.11.3.1.2 Activity data

Statistics Norway supplied unpublished data on the application of organic fertilizer in settlements from 1990 to 2001. From 2022 onwards, data stratified by county was obtained from Statistics Norway (2022b). 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. 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). The data stratification by dry and wet climates followed the same procedure described in inorganic fertilizer on forest land (section 6.11.1.1.2).

6.11.3.1.3 Emission factor

The disaggregated emission factors used for organic fertilizer in settlements are shown in Table 6-49.

Table 6-49: Emission factors to estimate direct N_2O emissions from settlements fertilization.

Factor	Disaggregation	Default value	IPCC default
EF_1	Other N inputs in wet climates	0.006	IPCC 2019 Refinement, Vol. 4, Ch.11, table 11.1
	All N inputs in dry climates	0.005	IPCC 2019 Refinement, Vol. 4, Ch.11, table 11.1

6.11.4 Uncertainties

The IPCC 2019 Refinement, Vol. 4, Ch. 11, table 11.1 provides the uncertainty related to the default emissions factor for N_2O from N additions from mineral and organic fertilizer. In addition, the uncertainty for the activity data associated with the estimation of inorganic N applied to forest land and organic N applied to settlements was estimated by expert judgement. The uncertainties of the emission factor, activity data, and total values are shown in Annex 2.

6.11.5 QA/QC and verification

The QA/QC plan was performed according to the Tier 1 procedure.

6.11.6 Recalculations

See chapter 10.2.4. for numbers and explanations.

6.11.7 Planned improvements

No planned improvements.

6.11.8 Completeness

The reporting for Direct N_2O 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 practiced on a large scale in Norway. Thus, in CRF Table 4(II), we report only emissions from drained organic soils (including peat extraction) as these are mandatory to report. CO_2 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_4 and N_2O emissions from forest land, drained wetlands used for peat extraction, and other drained wetlands (mires). Further, we report N_2O and CH_4 emissions on subcategories of settlements which have organic soil. For croplands and intensive grasslands, only CH_4 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. Following the IPCC 2006 Guidelines, N_2O emissions from drained organic agricultural soils (cropland and grassland) are reported in the agriculture sector.

N_2O and CH_4 emissions from instant oxidation of removed peat on settlements are not reported due to no default method available.

Please note that CRF tables *Table4* and *Summary2* are inconsistent due to some emissions of CH_4 and N_2O 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_2O emissions from drainage of organic soils (key category)

The source category N_2O emissions from drained organic soils on forest land is identified as a key category. Details on identification criteria can be found in chapter 1.4.

6.12.1.1 Methodological issues

To estimate N_2O 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

For croplands and intensive grasslands, N_2O 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 are in the cool temperate climate zone. Emission factors for these two land uses are shown in Table 6-50. EFs for drained organic soils on settlements are shown in Table 6-52.

Table 6-50: Emission factors (N_2O) for drained organic soils.

Land use	Emission Factor (N_2O-N ha^{-1} yr^{-1})	Climate zone	Reference
Forest land	2.8	Temperate	IPCC 2013 Wetlands Supplement, Ch. 2, Table 2.5
Wetlands (peat extraction)	0.3		

6.12.2 CH_4 emissions from drainage of organic soils (key category)

The source category CH_4 emissions from drained organic soils on cropland is identified as a key category. Details on identification criteria can be found in chapter 1.4.

6.12.2.1.1 Methodological issues

To estimate CH_4 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

$$CH_4 = A \times ((1 - Frac_{ditch}) \times EFCH_{4\_land} + Frac_{ditch} \times EFCH_{4\_ditch})$$

where, A is the area of drained organic soil; $Frac_{ditch}$ is the fraction of the area occupied with ditches; and $EFCH_{4\_land}$ $EFCH_{4\_ditch}$ 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 $Frac_{ditch}$ of 6% for forest land and 4% for wetlands. According to Søgaard (2017) it is not possible to provide an accurate estimate for the fraction of ditches for cropland, grassland, settlements and for peat extraction in Norway. Therefore, based on the available data the default value of 5% (IPCC 2014) appears to be adequate for use.

6.12.2.1.2 Activity data

The drained forest soil and wetlands area was from registrations 2016-2022 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.

6.12.2.1.3 Emission factor

For drained forests and wetlands on organic soils, the default $EFCH_{4\_land}$ and $EFCH_{4\_ditch}$ in the temperate climate zone from the IPCC 2013 Wetlands supplement are shown in Table 6-51. For settlements, factors are given in Table 6-52 depending on sub-categories.

Table 6-51: Emission factors (CH_4) for drained organic soils.

Land use	Emission Factor $EFCH_{4\_land}$ (kg CH_4 ha^{-1} yr^{-1})	Emission Factor $EFCH_{4\_ditch}$ (kg CH_4 ha^{-1} yr^{-1})	Climate zone	Reference
Forest land	2.5	217	Temperate	IPCC 2013 Wetlands Supplement, Ch. 2, Tables 2.3 and 2.4
Wetlands (organic soil)	2.5	217		
Wetlands (peat extraction)	6.1	542		
Cropland	0	1165		
Grassland (shallow-drained, nutrient-rich)	39	527		

Table 6-52: Settlements subdivision classes and their associated Tier 1 EF's on organic soils. EF for CH_4 and N_2O are from Table 2.3, 2.4, and 2.5 in IPCC (2014).

Classes	kg N_2O-N $ha^{-1}yr^{-1}$	kg CH_4 $ha^{-1}yr^{-1}$	kg CH_4 $ha^{-1}yr^{-1}$ drainage ditches	Frac ditch
Temperate Climate Zone				
Paved (P)	1.6	39	527	0.05
Turfgrass (T)	8.2	16	1165	0.05
Vegetated (V)	1.6	39	527	0.05
Boreal Climate Zone				
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 (2014) are summarized in Annex 2.

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

See chapter 10.2.4. for numbers and explanations.

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_2O emissions from N mineralization and immobilization – 4(III)

In the IPCC 2019 refinements, direct N_2O 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_2O 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

6.13.1.1.1 Choice of method

To estimate N_2O emissions from N mineralization, we first calculate the net annual amount of N mineralized in mineral soils resulting from SOC loss (F_{SOM}) from

$$F_{SOM} = \Delta C \times 1/\ CN \qquad \text{Equation 11.8; (IPCC 2006)}$$

where *ΔC* is the average annual C loss from mineralization of soil for each land-use type for wet and dry climate (in kt C yr^{-1}), and CN is the C/N ratio for soils. To estimate the N_2O emissions from N mineralization, we multiply F_{SOM} with the default emission factors for wet and dry climate, 0.014 and 0.005 N_2O-N (kgN^{-1}), respectively. We consider the method a Tier 1 because we use the default C/N ratios (CN = 15, and CN = 10 for cropland remaining cropland), 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) can result in positive SOC stock changes in the mineral soil pool, thus, no N_2O emissions are reported from these sub-categories.

6.13.1.1.2 Activity data

Activity data used for this source is the annual average C losses stratified by wet and dry climate. This data is reported aggregated in 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

See chapter 10.2.4. for numbers and explanations.

6.13.3 Planned improvements

No planned improvements.

6.13.4 Completeness

Reporting from source 4(III) Direct N_2O emissions from N mineralization and immobilization is complete.

6.14 Indirect N_2O emissions from managed soils – 4(IV)

Indirect N_2O emissions occur through two pathways: 1) the volatilization of N as NH_3 and NO_X 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 2019 Refinement methodology for estimating indirect emissions includes N inputs from several sources (Equation 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_2O 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 2019 Refinements 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

$$N_2O\text{-}N = (Frac_{GASF} \times F_{SN} + F_{ON} \times Frac_{GASM}) \times EF_{vol} \qquad \text{Equation11.9; (IPCC 2006).}$$

Default values are applied where $Frac_{GASM}$ = 0.21, $Frac_{GASF}$ = 0.05 (ammonium-nitrate-based), and EF_{vol} = 0.014 and 0.005 kg N_2O-N (kg N)$^{-1}$for wet and dry climate regions, respectively.

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} = 0.011 kg N_2O-N (kg N leaching/runoff)$^{-1}$ by

$$N_2O_{(L)}\text{-}N = (F_{SN} + F_{ON} + F_{SOM}) \times Frac_{LEACH} \times EF_{leach}$$

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 0.24.

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 has a major influence on the emissions from atmospheric deposition. 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.

The uncertainties from the different emission factors are default values from the IPCC 2019 Refinement. Uncertainties for activity data, emission factors and aggregated uncertainties for atmospheric deposition and leaching can be found in Annex 2.

6.14.4 QA/QC and verification

The QA/QC plan was performed according to the Tier 1 procedure.

6.14.5 Recalculations

See chapter 10.2.4. for numbers and explanations.

6.14.6 Planned improvements

There are no planned improvements.

6.14.7 Completeness

Reporting from source 4(IV) Indirect N_2O emissions from managed soils is complete.

6.15 Biomass Burning – 4(V)

Emissions of CO_2, CH_4, and N_2O 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 practiced, 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_2 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_2 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_2 gases from forest fires exist. N_2O and CH_4 emissions from forest wildfires are estimated using a Tier 1 method from the IPCC 2006 Guidelines. The following Equation 2.27 is used:

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3}$$

where L_{fire} = amount of greenhouse gas (CO_2, CH_4, and N_2O) from fire (tonnes), A = area burnt (ha), M_B = mass of fuel available for combustion (tonnes ha^{-1}), C_f = combustion factor (dimensionless), and G_{ef} = emission factor (g kg^{-1} dry matter burnt). Activity data (area burnt) is based on country-level estimates. Values used for M_B and C_f are derived by considering 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 6-53.

Table 6-53: Estimates of CO_2, CH_4, and N_2O emissions (kt CO_2 equivalents) from forest fires.

Year	CO_2 (kt)	CH_4 (kt CO_2 eq)	N_2O (kt CO_2 eq)	SUM (kt CO_2 eq)
1990	9.75	0.82	0.43	11.00
1991	16.40	1.38	0.72	18.49
1992	15.05	1.26	0.66	16.97
1993	2.79	0.23	0.12	3.14
1994	3.17	0.27	0.14	3.57
1995	1.25	0.11	0.06	1.41
1996	8.77	0.74	0.39	9.89
1997	9.42	0.79	0.41	10.62
1998	3.45	0.29	0.15	3.90
1999	0.71	0.06	0.03	0.80
2000	1.49	0.13	0.07	1.68
2001	0.61	0.05	0.03	0.68
2002	2.89	0.24	0.13	3.26
2003	6.09	0.51	0.27	6.86
2004	1.22	0.10	0.05	1.38
2005	3.58	0.30	0.16	4.03
2006	32.43	2.72	1.42	36.57
2007	2.53	0.21	0.11	2.86
2008	51.50	4.32	2.26	58.08
2009	8.90	0.75	0.39	10.04
2010	14.62	1.23	0.64	16.49
2011	1.94	0.16	0.09	2.19
2012	0.77	0.06	0.03	0.87
2013	0.53	0.04	0.02	0.60
2014	5.94	0.50	0.26	6.70
2015	0.87	0.07	0.04	0.98
2016	4.35	0.37	0.19	4.91
2017	3.50	0.29	0.15	3.95
2018	18.72	1.57	0.82	21.12
2019	14.01	1.17	0.62	15.80
2020	3.25	0.27	0.14	3.67
2021	7.63	0.64	0.34	8.61
2022	25.95	2.18	1.14	29.26

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 1993–2022. 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^3 ha^{-1}, respectively (Granhus et al. 2012). In biomass, this equals 12 and 55 t ha^{-1}, 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^3 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_2 estimates provided in Table 6-53 are for comparison only and to enable estimation of N_2O and CH_4 emissions, and thus, not used in the reported CO_2 emissions.

Table 6-54: Information on forest fires in Norway and estimated CO_2 emissions.

Year	Number of fires	Unproductive forest (ha)	Productive forest (ha)	Area burned (ha)
1990*	578.0	679.6	256.4	936.0
1991*	972.0	1142.9	431.3	1574.2
1992*	892.0	1048.9	395.7	1444.6
1993	253.0	135.5	88.3	223.8
1994	471.0	123.6	108.1	231.7
1995	181.0	77.6	35.5	113.1
1996	246.0	169.7	343.8	513.5
1997	533.0	605.8	260.6	866.4
1998	99.0	164.7	110.3	275.0

1999	148.0	73.4	12.7	86.1
2000	99.0	142.6	29.3	171.9
2001	117.0	84.3	5.2	89.5
2002	213.0	124.7	95.8	220.5
2003	198.0	905.6	36.8	942.4
2004	119.0	84.6	32.3	116.9
2005	122.0	252.4	93.2	345.6
2006	205.0	3222.2	606.7	3828.9
2007	65.0	22.2	106.1	128.3
2008	171.0	1210.2	1963.6	3173.8
2009	109.0	1257.9	70.8	1328.7
2010	62.0	165.9	602.8	768.7
2011	49.0	47.8	73.4	121.2
2012	24.0	35.1	24.9	60.0
2013	40.0	30.8	15.6	46.4
2014	133.0	681.7	87.7	769.4
2015	40.0	141.6	2.0	143.6
2016	248.0	434.9	80.8	515.7
2017	191.0	368.1	60.4	428.5
2018	771.0	1572.0	424.1	1996.1
2019	200.0	2231.2	47.2	2278.4
2020	291.0	294.8	68.2	363.0
2021	263.0	425.0	228.2	653.2
2022	262.0	1761.5	694.5	2456.0

*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_2 emission factor of 70% IPCC (2003) and expert judgement on the activity data.

6.15.1.3 Recalculations

See chapter 10.2.4. for numbers and explanations.

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_2 for controlled forest fires and grassland wildfires are reported as NE.

6.15.1.5.1 Non-significant emissions: Controlled forest fires, CH_4, N_2O

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_2 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).

To evaluate this emission as "non-significant", it was related to the Norwegian emissions from all sectors except the LULUCF sector, as explained in chapter 1.7.

6.15.1.5.2 Non-significant emissions: Grassland wildfires, CH_4, N_2O

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.

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.

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_2 emissions (IPCC 2006 Guidelines, Vol. 4, Equation 2.27) with the following input values:

- A = sum of area (ha) in each year,
- M_B*C_f = 11.5 tonnes ha^{-1} (shrublands vegetation type, subcategory *Calluna* heath (IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.4).
- G_{ef} CH_4 = 4.7 g kg^{-1}, G_{ef} N_2O = 0.26 g kg^{-1} (IPCC 2006 Guidelines, Vol. 4, Ch. 2, Table 2.5 "Extra tropical forest").

CO_2 equivalents of CH_4 and N_2O were calculated from Equation 2.27, where the CH_4-CO_2 eq = L_{fire} * 28 or N_2O-CO_2 eq = L_{fire} * 265.

To evaluate this emission as “non-significant”, it was related to the Norwegian emissions from all sectors except the LULUCF sector, as explained in chapter 1.7.

7. Waste (CRF sector 5)

7.1 Overview of the sector

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_2 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 46.4% (1.2 million tonnes CO_2 equivalents) from 1990 to 2022. The reductions were mainly due to decreased CH_4 emissions from landfills. Indeed, they decreased by 62.1% from 1990 to 2022, corresponding to 1.4 million tonnes CO_2 equivalents. Emissions from wastewater treatment decreased by 0.07 million tonnes CO_2 equivalents during the same period. Emissions from waste incineration without energy utilization and biological treatment of waste increased their emissions by 0.2 and 0.06 million tonnes CO_2 equivalents, respectively.

Solid waste disposal on land (i.e., in landfills) is the main emission category within the waste sector, accounting for, in 2022, 61.2% of the sector's total emissions. Wastewater handling in domestic and industrial sectors account for 16.4 and 2.5% of the sectors emission. Biological treatment of waste accounts for 4.6% of emissions from the waste sector and waste incineration, without energy recovery, accounts for 15.4%.

The waste sector accounted for 2.9% of the total GHG emissions in Norway in 2022. 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	Identification criteria	Method
5A1	Managed Waste Disposal on Land	CH_4	Level and trend approach 1, Level and Trend approach 2	Tier 2
5B	Biological treatment of Solid Waste	CH_4	Trend approach 2	Tier 1
5D1	Domestic wastewater treatment and discharge	CH_4	Level approach 2	Tier 1

Source: Statistics Norway/Norwegian Environment Agency

7.2 Anaerobic managed waste disposal sites, 5A1a (Key category for CH_4)

7.2.1 Category description

CH_4 and non-fossil CO_2 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_2. When there is no more oxygen left, the decomposition becomes anaerobic, and methane emissions start to increase. After a year or so, CH_4 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 1st 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 2022, 62 landfills, which had installed a landfill gas extraction system, reported extraction of gas. 4 608 tonnes of methane were recovered representing a 2.5% increase compared to 2021. 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 69% from 1995 to 2022, 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 1st 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 31st 2012.

In 2022, methane emissions from managed waste disposal sites were 0.9 million tonnes CO_2 equivalents.

According to the approach 1 and 2 key category analyses are emissions of CH_4 from Anaerobic Managed Waste Disposal sites (CRF 5A1a) a key category in level and trend assessment (1990-2022).

It should be noted that the IEF for CH_4 varies mainly due to the reduction in the amount of waste deposited and due to variation of the amount of extracted CH_4 from the landfills.

There are no known semi anaerobic disposal sites in Norway, according to expert judgment (Skullerud, Pers. Comm)[53], 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.

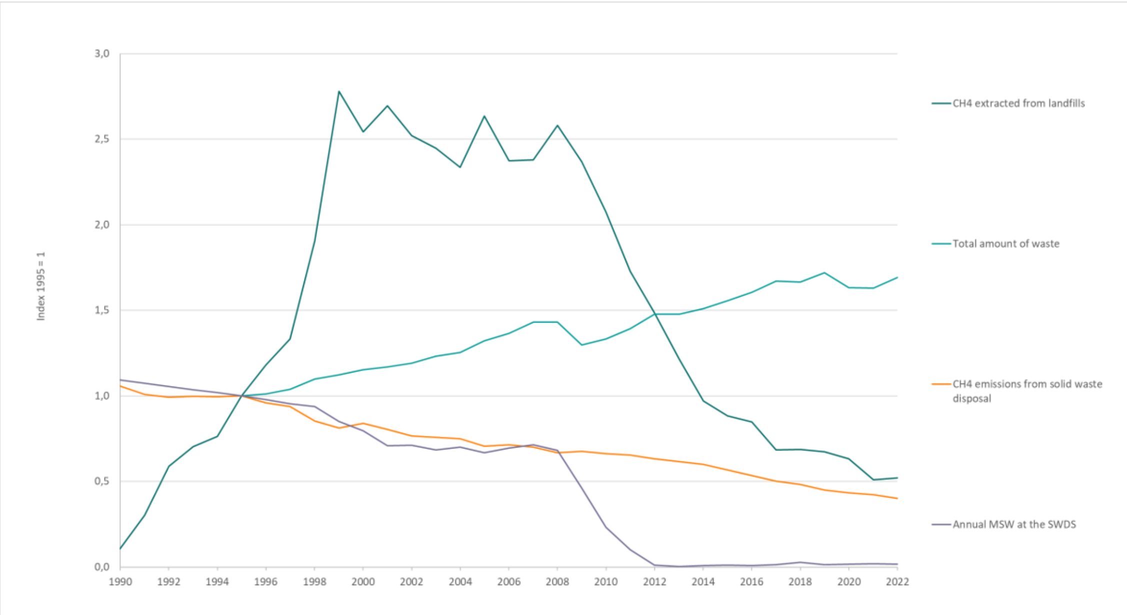


Figure 7.1: Relative change in methane emissions from solid waste disposal, annual MSW at the SWDS, methane extracted from landfills and total amount of waste generated in Norway. 1990-2022 Index 1995 = 1. Source: Statistics Norway/Norwegian Environment Agency.

[53] Håkon Skullerud 2014: Personal communication by telephone. Statistics Norway

7.2.2 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 1st the year following the landfilling, the “motor” of the new calculating model has been made from these two very simple equations:

(7.1) $$DDOC_{mdiss} = \left(DDOC_{ma(ly)} + DDOC_{md}\right) \times \left(1 - e^{-k}\right)$$

(7.2) $$DDOC_{ma} = \left(DDOC_{ma(ly)} + DDOC_{md}\right) \times e^{-k}$$

Equation (7.1) calculates DDOCmass decomposing ($DDOC_{mdiss}$) as the sum of the not decomposed DDOC mass accumulated from the previous years ($DDOC_{ma(ly)}$), and the DDOC mass landfilled during the previous year ($DDOC_{md}$).

Equation (7.2) calculates the DDOC mass accumulated as not decomposed ($DDOC_{ma}$), which is then used as ($DDOC_{ma(ly)}$) for the following year’s calculations using equation (7.1).

The mass of decomposable organic carbon landfilled ($DDOC_{md}$) is estimated using equation (7.3).

(7.3) $$DDOC_{md} = W \times MCF \times DOC \times DOC_f$$

The amount of decomposed $DDOC_m$ being estimated, CH_4 produced, and CH_4 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 1st 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) $$DDOC_{mdi} = DDOC_{md} \times \left(1 - e^{-k \times \left(\frac{13-M}{12}\right)}\right)$$

(7.5) $$DDOC_{mdiss} = DDOC_{ma(ly)} \times \left(1 - e^{-k}\right) + DDOC_{mdi}$$

Equation (7.2) must be replaced by equations (7.6) and (7.7).

(7.6) $$DDOC_{ml} = DDOC_{md} \times e^{-k \times \left(\frac{13-M}{12}\right)}$$

(7.7) $$DDOC_{ma} = DDOC_{ma(ly)} \times e^{-k} + DDOC_{ml}$$

The amount of methane produced from decomposition of DDOC is estimated using equation (7.8).

$$(7.8) \quad CH_{4\,prod} = DDOC_{mdiss} \times F \times {}^{16}/_{12}$$

Methane emissions are estimated from the amount of methane produced and the amount of methane recovered. Equation (7.9) details the calculations.

$$(7.9) \quad CH_{4\,emitted\ in\ year\ T} = \left(\sum CH_{4\,prod}\,(T) - R(T)\right) \times (1 - OX)$$

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_f : Fraction of DOC decomposing, anaerobic conditions

$DDOC_m$: Mass of Decomposable Organic Carbon, anaerobic conditions

$DDOC_{md}$: DDOC mass landfilled

$DDOC_{ml}$: DDOC mass left not decomposed from DDOCm landfilled, year of landfilling

$DDOC_{ma}$: DDOC mass left not decomposed at end of year

$DDOC_{ma(ly)}$: DDOC mass accumulated from last year

$DDOC_{mdi}$: DDOC mass decomposed from DDOCm landfilled, year of landfilling

$DDOC_{mdiss}$: DDOC mass decomposed in calculation year

$CH_{4\ prod}$: CH_4 produced

F : Fraction of CH_4 by volume in generated landfill gas

16/12 : Conversion factor from C to CH_4

R(T) : Recovered CH_4 in year of calculation

OX : Oxidation factor (fraction).

7.2.3 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.

<u>Municipal landfills</u>

Historical data for years before 1973 on municipal solid waste deposited are based upon:

1. New statistics on municipal waste, divided into household waste and industrial waste (1974 to 1997),
2. Estimates based on population,
3. 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 adaptions:

- 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 * landfilled ‘other materials’ from manufacturing + 0.5 * '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, 1945-2022. 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
2022	0	0	3	0	6	11

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	1 936	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

7.2.4 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_f (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.

7.2.5 Uncertainties and time-series consistency

The amount of different waste materials is considered to be known within ±20%. The emission factors used are considered to have the uncertainty range ±30%. More information about the uncertainty estimates for this source is given in Annex 2.

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, 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.

7.2.6 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.

7.2.7 Recalculations

Revised activity data. Recovered amounts of methane are updated in the period 2017-2021 due to new information. More details on the recalculation are given in chapter 10.

7.2.8 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 Composting and Anaerobic digestion of organic waste – 5B1 and 5B2

7.4.1 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_2). CH_4 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_2O.

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_4, N_2O and CO_2 are emitted during this process. CO_2 emissions from compost production are biogenic.

According to the approach 2 key category analyse are emissions of CH_4 from Biological treatment of solid waste (CRF 5B) a key category in trend assessment (1990-2022).

7.4.2 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_4 emissions from biological treatment

(7.10) $$CH_4\ Emissions = \sum_i (M_i * EF_i) * 10^{-3}$$

Where:

CH_4 Emissions : total CH_4 emissions in inventory year, Gg

M_i : mass of organic waste treated by biological treatment type *i*, Gg

EF : emission factor for treatment *i*, g CH_4/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_4 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_2. Anaerobic sections are inevitable and cause emissions of CH_4. In the same manner, aerobic biological digestion of N leads to emission of N_2O (IPCC 2006).

N_2O emissions from composting

(7.11) $N_2O\ Emissions = \sum_i (M_i * EF_i) * 10^{-3}$

Where:

N_2O Emissions : total N_2O emissions in inventory year, Gg

M_i : mass of organic waste treated by biological treatment type i, Gg

EF : emission factor for treatment i, g N_2O/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.

7.4.3 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 and in addition from the database Forurensing (Norwegian Environment Agency) from 2017. 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.

Table 7-5: Amount of waste biologically treated at composting and biogas facilities, 1990-2022. Tonnes of waste on wet basis.

Year	Composting	Anaerobic digestion, solid waste	Anaerobic digestion, 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	190 000	285 000	998 116
2018	180 000	288 000	1 208 303
2019	166 000	365 000	1 106 765
2020	219 000	317 000	1 603 385
2021	225 000	359 000	1 113 825
2022	172 000	337 000	1 284 856

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.

Table 7-6: Number of households with home composting and amount of organic waste composed, 1990-2022. Tonnes wet basis.

Year	Number of households with home composting	Amount of organic waste composted
1990	52 541	8 111
1995	55 407	10 129
2000	58 273	12 484
2005	60 330	15 563
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	13 808
2019	63 549	14 329
2020	64 485	15 279
2021	65 453	14 728
2022	66 328	13 320

Source: Statistics Norway

7.4.4 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_4 and N_2O emissions from biological treatment for the Tier 1 method used in the Norwegian inventory (IPCC 2006). The CO_2 produced and emitted during composting is short-cycled C and is therefore regarded as CO_2 neutral (Boldrin et al. 2009).

Table 7-7: Biological treatment of waste: emission factors. kg/tonnes wet basis.

	Composting	Anaerobic digestion at biogas facilities	Home composting
CH_4	4	0.8	4
N_2O	0.24	NO	0.24

Source: IPCC (2006)

7.4.5 Uncertainties and time-series consistency

The amount of waste biological treated at composting and biogas facilities is considered to be known within ±20%. The amount of waste composted at home is considered to be known within ±100%. The emission factors used are considered to have the uncertainty range ±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.

7.4.6 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.

7.4.7 Recalculations

Recalculations have been performed for this source category, see chapter 10 for more details.

7.4.8 Planned improvements

Norway has collected plant specific activity data and participate into a technical exchange on GHG inventories related to waste. Results of the exchange will be used to implement a higher Tier methodology as recommended by the ERT.

7.5 Waste incineration – 5C

7.5.1 Category 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_2 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_2 and CH_4

Net CO_2 emissions from wood/ biomass burning are not considered in the Norwegian inventory, because the amount of CO_2 released during burning is the same as that absorbed by the plant during growth. Carbon emitted in compounds other than CO_2, e.g., as CO, CH_4 and NMVOC is also included in the CO_2 emission estimates. This double counting of carbon is in accordance with the IPCC guidelines (IPCC 2006).

Municipal waste incineration – N_2O

Emissions of N_2O are derived from the emissions of NO_X, which are reported from each plant to the Norwegian Environment Agency. More specifically, an estimated amount of 2.5% of this NO_X is subtracted and reported to UNFCCC as N_2O (SFT 1996). Accordingly, the net NO_X emissions constitute 97.5% of the emissions reported by the plants. For some years, emissions of NO_x 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_4 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_4, and amount of CH_4 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_4.

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	9 633	1 393	8 685
2011	7 456	1 495	7 818
2012	6 536	1 154	6 603
2013	5 616	971	5 132
2014	4 060	1 742	4 510
2015	4 368	902	3 433
2016	3 407	443	4080
2017	3 538	774	2 505

2018	3 584	991	2 483
2019	4 239	374	2 280
2020	3 747	858	1 836
2021	3 178	774	1 318
2022	3 074	1 033	1 534

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. Emission factor for waste incineration is given in chapter 3.

Table 7-10: Emission factors for flare and hospital waste incineration.

Component	Flare Landfill gas[1] and biogas kg/tonnes	Hospital waste Tonnes/tonnes
CO_2	0	0.3
CH_4	0.37	0.00023
N_2O	0.0015	0.000035

Source: [1]SFT (1996)

7.5.5 Uncertainties and time-series consistency

Activity data

Uncertainty estimates for greenhouse gases are presented and discussed in Annex 2.

The total amounts of waste in municipal waste incineration at each facility are considered to be of good quality and with low variation. There may be some uncertainty in the categorization of the waste, but as the fossil share has small variations between the different waste sources it is considered to have a low impact (MEPEX 2020).

No new data on the amount of hospital waste has been reported since 1999. The amount of hospital waste incinerated in the subsequent years may vary from the data reported in 1999 currently used in the inventory for the period 2000-2005.

Uncertainty in the activity data has been estimated to ±10%.

Emission factors

Uncertainty estimates for greenhouse gases are presented and discussed in Annex 2.

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 2.

The emission factor for CO_2 from municipal waste incineration have uncertainty regarding the fossil share in the burned waste. There is access to sorting analysis at municipal recycling/incineration facilities in the period of 2012-2019. The uncertainty connected to the fossil share is increased due to relatively old analysis, large differences between different facilities, lack of control on industrial waste and lack of analysis on imported waste.

Uncertainty in the CO_2 emission factor has been estimated to ±30%.

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

Recalculations have been performed for this source category, see chapter 10 for more details.

7.5.8 Planned improvements

There are no planned improvements in 5C.

7.6 Wastewater treatment and discharge – 5D (Key category for CH_4)

7.6.1 Overview

In 2022, wastewater handling accounted for 18.9% of the emissions in the waste sector. CH_4 and N_2O emissions from Wastewater handling have been reduced by 21.0% between 1990 and 2022. Emissions have been relatively stable since 1998.

Wastewater can be a source of methane (CH_4) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N_2O). Carbon dioxide (CO_2) 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_4 is produced. Emissions from the use of the produced CH_4 are included in the energy and industry sectors. Emissions of CH_4 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_2O 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 2 key category analysis is CH_4emissions from Domestic wastewater treatment and discharge (5D1) a key category in Level assessment (1990 and 2022).

The Norwegian wastewater treatment system is characterized by a few big and advanced aerobic wastewater treatment plants (WWTP) and many smaller WWTP. In 2022, 65% 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, 13% of the population was connected to small wastewater facilities (less than 50 pe) and the remaining 1% 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_4 and N_2O emission from wastewater handling, i.e., wastewater collection and treatment. CH_4 is produced during anaerobic conditions and treatment processes, while N_2O 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_4 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_4. 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, except for one, have aerobic treatment. 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_4

<u>CH_4 from domestic wastewater treatment plants</u>

Methane emissions from domestic wastewater have been calculated according to the IPCC default updated methodology (2019):

$$(7.12) \quad CH_4 Emissions = \sum_j EF_j \times \left(TOW_j - S_j\right) - R_j$$

Where:

U_i:	fraction of the population in income group i
$T_{i,j}$	Degree of utilisation of treatment/discharge j, for each income group i
EF_j	Emission factor for treatment/discharge j, kg CH_4 / kg BOD
TOW_j:	organics in wastewater of treatment/discharge pathway or system, j, in inventory year, kg BOD/yr.
S_j	Organic component removed as sludge from treatment/discharge pathway or system, j (kg BOD / yr)
R_j	Amount of CH_4 recovered from treatment/discharge pathway or system, j in the inventory yr.

Emissions have been estimated for all treatment types and for discharge into the 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_4 emissions are estimated according to IPCC updated methodology (2019).

7.6.2.1.2 N_2O

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_2O emissions from domestic wastewater treatment

N_2O 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_2O emissions occurring as a by-product in biological nitrogen-removal plants has also been included into the calculations.

N_2O 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_2O-N/kg N produced. Emissions in N needs to be converted into N_2O using the conversion ratio of N into N_2O: 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_2O 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_2O.

$$(7.14) \quad N_2O = N_{removed} \times 0.02 \times \frac{44}{28}$$

The amount of N removed is multiplied by 2% and emissions are then converted using the conversion ratio of N into N_2O: 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_4 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_0:	Maximum methane-producing capacity (kg CH_4/kg COD)
MCF:	Methane correction factor

N_2O 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_2O:	N_2O emissions in inventory, kg N_2O/year
$N_{Effluent}$:	content of nitrogen in the effluent
$EF_{Effluent}$:	emission factor for N_2O 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_4 and N_2O 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_4 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.

Table 7-11: Total organic product treated in domestic wastewater.

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
2022	143 919

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.

Table 7-12: Wastewater treatment organics removal fractions (TOWrem) according to treatment type.

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	39 562
2022	39 811

Source: Statistics Norway/ Norwegian Environment Agency

7.6.3.1.2 N_2O 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 from 1997. 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):

$$\text{(7.17)} \quad Potential\ protein\ intake\ = production\ + import\ - export$$

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.[54]). 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 g/person/day	kg/person/year	Index 1997 =100	Estimated protein intake kg/person/year
1990	**94**	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	**93**	33.9	99.5	31.22
1996	93.3	34.0	99.7	31.31
1997	**93.5**	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.

[54] Johansson, L. (2005): Personal information by telephone, Directorate for Health and Social Affairs

7.6.3.2 Industrial wastewater

7.6.3.2.1 CH_4 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 1990-2022.

Year	COD released into recipient from industrial WWTP (tonne)
1990	143 446
1995	124 982
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	45 336
2022	46 327

Source: Statistics Norway/ Norwegian Environment Agency

7.6.3.2.2 N_2O emissions from industrial WWTP

N_2O emissions from industries connected to large treatment plants (>50 pe) are included in domestic wastewater handling sector (CRF 5D1) while N_2O 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.

Table 7-16: Reported Nitrogen discharged by industries, in tonne/year, for the years 1990-2022.

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
2022	818

Source: Norwegian Environment Agency

7.6.4 Emission factors

7.6.4.1 CH_4 emissions from domestic WWTP

The default emission factor for B_0 of 0.6 kg CH_4/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.

Table 7-17: Part of the population connected to tanks with anaerobic conditions for the period 1990-2022.

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%
2022	86%	13%	1%

Source: Statistics Norway

7.6.4.2 CH_4 emissions industrial WWTP

The default emission factor for B_0 of 0.25 kg CH_4/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_2O emissions from large WWTP

N_2O emissions in **biological nitrogen removal-plants** have been estimated assuming that 2% of the nitrogen removed from the plants will form N_2O. 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_2O. In 2011, N_2O emissions were measured at various spots within the treatment plant, as well as the concentrations of N_2O in the liquid phase throughout, including the exit water. The results verified that the performance of this process, with respect to N_2O emission, is much better than the emission factor used for the other treatment plants. On the average, the emission of N_2O -N to air from the entire plant (through the chimney) amounted to 0.2% of the processed N. If the N_2O lost as dissolved N_2O 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 N_2O. 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 N_2O 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:

- EF_6: 0.005 kg N_2O/kg sewage-N produced has been used.
- $Frac_{NPR}$, the fraction of nitrogen in protein, has been set equal to 0.16 kg N/kg protein.

7.6.4.5 N_2O emissions from on-site industrial WWTP

IPCC default emission factor has been used for industries with on-site WWTP.

- $EF_{Effluent}$: 0.005kg N_2O/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 2. 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 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

Recalculations have been performed for this source category, see chapter 10 for more details.

7.6.8 Planned improvements

Emissions from the amount of CH_4 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

Norway does not report any emissions in the *Other* source category.

9. Indirect carbon dioxide and nitrous oxide emissions

- 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_2 species eventually oxidises to CO_2 in the atmosphere. The 2006 Guidelines further states that this can be estimated from the emission estimates of the non-CO_2 gases and that these CO_2 inputs could be included in national inventories. Norway includes such CO_2 inputs in its inventory, and these are referred to as indirect CO_2. The indirect CO_2 emissions from non-combustion sources originating from the fossil part of CH_4 and NMVOC are taken into account, calculated on the basis of average carbon content. Fossil carbon in the emissions of CH_4 and NMVOC from several non-combustion sources are included in the Norwegian emission inventory, see Table 9-1. The NMVOC emission estimates used to estimate indirect CO_2 emissions for the national GHG inventory are the same as those reported under the Convention on Long-Range Transboundary Air Pollution.

Most of these indirect CO_2 emissions are reported in CRF summary tables 2, 6 and 10. The indirect CO_2 emissions from 2D3 (solvent use) and 2D3 (road paving with asphalt) are however reported in the IPPU sector. This is in order to ensure the highest possible consistency with the guidance provided in the IPCC 2006 Guidelines related to the reporting of "Non-energy products from fuels and solvent use". This approach is also more transparent than the reporting in CRF summary table 6 where indirect CO_2 emissions are aggregated at sectoral level.

Table 9-1: Source categories in the inventory where indirect CO_2 emissions are calculated for CH_4 and NMVOC.

CRF code	Source category
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_2 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_2 emissions of CO would imply double counting.

9.1.2 Indirect nitrous oxide emissions

Indirect emissions of N_2O can occur by several pathways. The agriculture sector covers indirect emissions from deposition of NO_x and NH_3 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_2O from deposition of NO_X and NH_3 emissions from other sectors. These N_2O emissions are included as memo items in the inventory.

The coverage of the indirect N_2O emissions in CRF Table 6 is listed in Table 9-2 below and the energy sector is the primary source.

Table 9-2: Source categories in the inventory where indirect N_2O emissions is reported in CRF Table 6 as memo items.

CRF sector	Source category
1. Energy	Indirect N_2O from all emissions of NO_x and NH_3 in the energy sector
2. IPPU	Indirect N_2O from all emissions of NO_x and NH_3 in the IPPU sector
3. Agriculture	Indirect N_2O from emissions of NO_x and NH_3. in source category 3F Field burning of agricultural residues. All other indirect N_2O emissions from agricultural NO_x and NH_3 are included in the inventory proper in source category 3D.
4. LULUCF	No estimated NO_x and NH_3 emissions and thus no indirect N_2O emissions.
5. Waste	Indirect N_2O from all emissions of NO_x and NH_3 in the waste sector *except* NH_3 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_2 emissions from oxidised CH_4 and NMVOC are calculated from the content of fossil carbon in the compounds. For CH_4, 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 value for carbon fraction, 0.85, is used. This leads to the emission factors 2.75 kg CO_2/kg CH_4, and 3.12 kg CO_2/kg NMVOC. The NMVOC factor is used for most source categories with the exceptions of the following sources:

- Sources with specific emission factor of 3.13 kg CO_2/kg NMVOC
  - 1B2a5 gasoline distribution (same as the emission factor as for combustion of gasoline)
- Sources with specific emission factor of 3 kg CO_2/kg NMVOC (from CMR Instrumentation (CMR 2011))
  - 1B2a3 transport
  - 1B2a4 refining/storage
  - 1B2b6 gas terminal
  - 1B2bc venting
  - 2B8b ethylene/VCM
  - 2B8g plastic
- Sources with specific emission factor of 2.2 kg CO_2/kg NMVOC
  - 2B8a methanol
  - 2D3 solvent use
  - 2D3 road paving with asphalt

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_2O emissions from deposition of NO_x and NH_3 are estimated according to the method in 2019 Refinement vol. 4 ch. 11, Table 11.3 to the IPCC 2006 Guidelines (IPCC 2006). The IPCC default emission factor of 0.01373 kg N_2O-N/(kg NH_3-N+NO_x-N volatilized) is used to calculate indirect emissions of N_2O from volatilized NH_3 and NO_x. The factor is taken from the methodology for indirect emissions in the agriculture sector, considering shares of 3% dry and 97% wet climate in Norway.

9.3 Uncertainty assessment and time-series consistency

Uncertainty estimates for greenhouse gases are given in Annex 2. 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 4 and the specific QA/QC carried out for indirect CO_2 emissions in the relevant source categories in Energy and IPPU are found in chapters 3 and 4 of the NIR.

The indirect N_2O emissions are based on NO_x and NH_3 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

Reallocation. The indirect emissions of CO_2 from emissions of NMVOC from 2D3 Solvent use and 2D3 Road paving with asphalt are now reported in the IPPU sector. They were in the 2023 NIR reported in CRF summary tables 2, 6 and 10.

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, including in response to the review process

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.

This section 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 this section. 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 10.2 and 10.3. An overview of issues identified by the UN review team and Norway's responses to these issues can be found in the section 10.4.

10.1.1 Specific description of the recalculations

10.1.1.1 Energy

Most of the recalculations have been performed for the inventory year 2021, 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.

10.1.1.1.1 1A1aiii Heat Plants

Updated emission factor. The emission factor for CO_2 from waste incineration is updated. This led to an increase in the CO_2 emissions. Details are found in section 10.1.1.5.4. There has also been a reallocation between 1A1Aiii and 5C12A which affects the emissions om CO_2 and N_2O in the whole time series.

10.1.1.1.2 Recalculation of emissions of CH_4 and NMVOC

During 2023, there has been a recalculation of emissions of CH_4 and NMVOC from land-based companies associated with the oil industry. The emissions have been revised throughout the entire time series, back to 1990. The following sources are affected by this recalculation:

1A1ai – Electricity generation
1A1B – Petroleum refining
1A1C - Manufacture of Solid Fuels and Other Energy Industries
1B2A – Fugitive emissions – oil from energy production
1B2B - Fugitive emissions – gas from energy production
1B2C – Venting and flaring

10.1.1.1.3 1A2, 1A3, 1A4

Revised activity data. The input statistic “Energy Use in Manufacturing Industries” went through quality control, resulting in revised activity data for many industries. Figures for total energy use were not changed, however the distribution of the total energy use to different industries was adjusted. Due to these changes many CRF sources were recalculated in the period 2010-2021, most sectors affected between 2017 - 2021. The affected sources are:

1A2a Iron and steel
1A2b Non-ferrous metals
1A2c Chemicals
1A2e Food processing, beverages, and tobacco
1A2d Pulp and paper
1A2f Non-metallic minerals
1A2gi Manufacturing of machinery
1A2gii Manufacturing of transport equipment
1A2giii Mining and quarrying
1A2giv Wood and wood products

1A2gv Construction
1A2gvi Textile and leather
1A2gvii Off-road vehicles and other machinery
1A2gviii Other
1A3biCars
1A3bii Light duty trucks
1A3biii Heavy duty trucks and buses
1A3biv Motorcycles
1A4ai Stationary combustion
1A4aii Off-road vehicles and other machinery
1A4bi Stationary combustion
1A4bii Off-road vehicles and other machinery
1A4ci Stationary
1A4cii Off-road vehicles and other machinery

10.1.1.1.4 1A2f Non-metallic minerals

Reallocation of CO_2 emissions from combustion to process use (2A4d) in the period 1990 to 2021 reported by one plant. This is because some of the waste oil is mixed into the clay as an additive and not used for combustion. Approximately 3 kt CO_2 are reallocated each year in the time series.

10.1.1.1.5 1A3a Civil aviation/1A5B Military

Activity data from respondents on jet kerosene has been updated and resulted in changes in domestic and international activity and emissions for the years 2018-2021. All biofuels are allocated in domestic aviation.

10.1.1.1.6 1A3b Road transportation

Road transport is affected by the revision of activity data in the energy balance, and the emissions are recalculated for the years 2010-2021.

The CH_4 and N_2O factors on CNG and natural gas in heavy duty vehicles are updated, now using the Handbook on Emission Factors for road transport (HBEFA) as source.

10.1.1.1.7 1A4bii Off-road vehicles - households

Emissions from gasoline and bio gasoline are recalculated in 2017-2021 due to updated activity data on snow scooters.

10.1.1.2 Industrial processes and product use

There are some recalculations for the IPPU sector, see details below.

10.1.1.2.1 2A4d Other process use of carbonates

Reallocation of CO_2 emissions from combustion (1A2f) to process use in the period 1990 to 2021 reported by one plant. This is because some of the waste oil is mixed into the clay as an additive and not used for combustion. Approximately 3 kt CO_2 are reallocated each year in the time series.

10.1.1.2.2 2B8a Methanol production

Recalculation of emissions of CH_4 for the period 1997 – 2021 due to a new method used by the plant for measuring and reporting CH_4 emissions. The new method results in lower CH_4 emissions for most years except 1997, 2015, 2017 and 2019 which have a small increase.

10.1.1.2.3 2.D.2 Paraffin wax use

Activity data for sold production of candles has been updated, resulting in recalculations of CO_2 emissions for the years 2013 – 2021. The change in activity data resulted in a decrease of CO_2 emissions in the range of 0.2 – 1.9 kt.

10.1.1.2.4 2.D.3 Solvent use and 2.D.3 Road paving with asphalt.

Reallocation. The indirect emissions of CO_2 from emissions of NMVOC are now reported in the IPPU sector. This is to ensure the highest possible consistency with the guidance provided in the IPCC 2006 Guidelines related to the reporting of "Non-energy products from fuels and solvent use" and the description of reporting categories under 2D in Volume 1, chapter 8, table 8.2 of the 2006 IPCC Guidelines.

10.1.1.2.5 2.E.1 Integrated circuit or semiconductor

Recalculation and reallocation. New information from the two producers have been obtained and the time series for the years 2003-2021 is recalculated. The emissions have decreased in the range of 18 to 182 tonnes CO_2 equivalents. The emissions previously reported in 2E1 are now reported as included elsewhere as the emissions are due to confidentiality reported in 2G1.

10.1.1.2.6 2F1 Refrigeration and Air conditioning

The methodology for the subsectors 2F1a, 2F1c, 2F1d and 2F1f is updated. Previously, the emission factors for the end-of-life treatment in the HFC/PFC calculation were not fixed. Instead, the calculations exclusively used activity data on quantities that have been decommissioned and sent for destruction as recovered amount of F-gas. This approach led to an overestimation of emissions from end-of-life. In the updated methodology, the calculation has been extended so that reused F-gas also is included.

The main consequences of this update are that emissions from end-of-life are reduced, while the total bank becomes larger and that emissions from leakages increase.

Other recalculations:

- 2F1b, updated activity data in 2020 and 2021. Recovery from domestic units is included due to access to new information. Emissions are hence reduced compared to the 2023 submission.
- 2F1e, correction of error. An error in the calculation was edited resulting updated emissions from leakage from 2011 to 2021 for all gases. In addition, the amount of recovered F-gas is higher than in the previous submission. This is because recovery is reported as the total of reused and destroyed F-gas in the present submission, while it was reported as destroyed amounts in the 2023 submission.
- 2F1 and 2F6, correction of error. Emissions are updated in the whole time series, due to a correction in the calculation of new products.

The effect on the recalculations on F-gases in 2F1 and 2F6 are presented in Table 10-1 below.

Table 10-1: Recalculated HFC and PFC emissions in 2F1 and 2F6, kt CO_2 eq and percentage change.

	HFC and PFC emission, kt CO_2 eq			
Year	**NIR 2024**	**NIR 2023**	**difference**	**Percentage change**
1990	0.05	0.05	0.00	1.7
1995	92.47	91.90	0.57	0.6
2000	359.76	356.68	3.08	0.9
2005	521.82	528.11	-6.29	-1.2
2010	761.14	855.47	-94.33	-11.0
2011	822.67	923.20	-100.53	-10.9
2012	869.42	979.91	-110.49	-11.3
2013	925.79	1068.12	-142.33	-13.3
2014	914.13	1028.05	-113.92	-11.1
2015	871.62	909.85	-38.24	-4.2
2016	878.88	950.73	-71.85	-7.6
2017	893.66	972.63	-78.96	-8.1
2018	833.93	939.66	-105.73	-11.3
2019	830.99	874.50	-43.51	-5.0
2020	775.99	749.80	26.19	3.5
2021	743.17	628.42	114.75	18.3

10.1.1.2.7 2.G.1 Electric equipment

Recalculation and reallocation. New information from the two producers have been obtained and the time series for the years 2003-2021 is recalculated. The emissions have decreased in the range of 18 to 182 tonnes CO_2 equivalents. The emissions previously reported in 2E1 are now reported as included elsewhere as the emissions are due to confidentiality reported in 2G1.

10.1.1.3 Agriculture

10.1.1.3.1 Animal population

In previous submissions, the number of pigs in category sows, boars, piglets, fattening pigs and young pigs for breeding were based on data from production subsidies. In the 2024 submission the animal count for pigs is now based on slaughter data, where the number of slaughtered pigs (fattening pigs) per year is the basis for the number of pigs in other pig categories. Number of days animals in each production stage is the main variable used to derive animal numbers. This methodology is a result of a project from NIBIO and the swine production corporation Norsvin SA (Bonesmo & Gjerlaug-Enger 2022). Activity data is provided by Norsvin SA. Implementing this method led to 24% lower animal numbers on average per year compared to previous submissions. The fall in the number of pigs can be explained by a former overestimation. The new animal year number now considers days with empty stables, which is standard practice in Norwegian pig production.

10.1.1.3.2 3A CH_4 from enteric fermentation

In 2024 submission a new model for dairy cattle was implemented. This led to 10% lower CH_4 emissions per year through the time series. The change in results between the old and new calculation is due to the inclusion of the dry period in the milk production cycle in the new model, in addition to updated terms for concentrate feed and fat content in the diet. These changes correct for overestimations made in the previous model. A more detailed explanation is given in Volden et al. (2023).

In the 2024 submission the enteric methane emission estimates for pigs are updated with a Tier 2 method. The update is based on a project from 2021 from NIBIO and the swine production corporation Norsvin SA (Bonesmo & Gjerlaug-Enger 2022). In the previous estimation, Tier 1 emission factors were used for all swine categories, while in the new model factors are estimated for piglets (weaners), young pigs for breeding (gilts), pigs for slaughter (finishers), sows and boars. Together with the new population figures for swine the difference in total between new and old calculation was 43% lower methane emission per year through the time series.

For goats, the updated emission factor from 2019 IPCC refinements to the 2006 Guidelines was used in 2024 submission (IPCC 2019). This led to 30% lower methane emissions through the time series.

10.1.1.3.3 3B N_2O and CH_4 from manure management

In 2023, a project for evaluating and updating existing N_{ex} and VS factors for swine was performed by the Norwegian University of Life Sciences (NMBU) (Kjos 2023). The N-factors were updated for five swine categories in 2022. Factors for boars and piglets were updated back to 1990 due to new information about the production of these animals. For the other categories: sows, slaughter pigs and young pigs for breeding a linear interpolation between 2012 and 2022 led to change in this period. Together with updated animal numbers the difference between previous and updated submission was 1% higher N_2O emissions from 1990-2014 and 10% lower emissions from 2014 to 2021.

The VS factors for pigs are estimated based on dry matter values:

VS tonnes/ year = (manure dry matter x 0.9*) x number of animals/ 1000

- ** expert estimate by Kjos, based on values from faecal analyses in digestibility experiments with pigs at NMBU*

The dry matter values were updated for the same five swine categories for 2022. The values were recalculated from 2012 to 2022. The values between 2012 and 2022 were a result of linear interpolation. For boars and piglets, the dry matter values were changed for the whole time series based on updated information about the production process. In total the changes in VS factors led to 10% lower methane emissions per year as an average compared to the 2023 submission.

The Nex factor for the young cattle group, heifer for slaughter, was also updated in the 2024 submission. This led to 1% lower N_2O emissions from 1990 to 2012 for young cattle and 1% higher emissions from 2013 to 2021 compared to earlier submission.

10.1.1.3.4 103Bb5 Indirect N_2O from manure management

The 2019 IPCC refinements to the 2006 Guidelines emission factors were implemented for indirect N_2O from manure management. The emissions factors are used according to Table 11.3 in IPCC 2019 refinements to the 2006 IPCC Guidelines (IPCC 2019). The factors for atmospheric deposition are climate adjusted based on the distribution of 97% wet- and 3% dry climate in Norway. The climate distribution for Norway is given by National Forest Inventory data from NIBIO[55].
For atmospheric deposition the emission factor changed from 0.01 to 0.01373 kg N_2O-N/(kg NH_3-N+NO_X-N volatilized) (IPCC 2019). This led to 36% higher emissions of N_2O

[55] Christian Mohr, NIBIO, personal communication 25.09.2023.

compared to former calculation. For leaching the emission factor changed from 0.0075 to 0.011 kg N_2O-N/kg N lost to leaching/runoff. This gave 47% higher N_2O emissions from leaching.

10.1.1.3.5 3D N_2O emissions from managed soils

IPCC Tier 2 methodologies and disaggregated default emission factors (IPCC 2019) have been implemented for estimating direct and indirect N_2O emissions from managed soils. The factors are climate adjusted based on the distribution of 97% wet- and 3% dry climate in Norway. The climate distribution for Norway is given by National Forest Inventory data from NIBIO[56]. The emissions factors are used according to Table 11.1 and 11.3 in IPCC 2019 refinements to the 2006 IPCC Guidelines (IPCC 2019).

10.1.1.3.6 3Da1 Inorganic N fertilizers

An emission factor based on the aggregated IPCC default factors for dry and wet climate (IPCC 2019) was implemented for emission from inorganic fertilizers. The factor was changed from 0.01 to 0.0157 kg N_2O-N/kg N applied. This led to 57% higher N_2O emissions compared to former estimation.

10.1.1.3.7 3D2a Animal manure applied to soils

In the 2024 submission an emission factor based on the aggregated IPCC default factors for dry and wet climate (IPCC 2019) for N_2O from spreading of animal manure were implemented. The emission factor was changed from 0.01 to 0.00597 kg N_2O-N/kg N applied. This led to 41% lower N_2O emissions compared to former submission.

10.1.1.3.8 3Da2 Sewage sludge and other organic fertilizer applied to soils

In the 2024 submission the climate adjusted IPCC 2019 refinements emission factors for N_2O were implemented by the same factor as for animal manure applied to soils. This led to 40% and 61% lower N_2O emissions for the time series compared to former submission for sewage sludge and other organic fertilizer respectively.

10.1.1.3.9 Urine and dung deposited by grazing animals, 3Da3

In the 2024 submission the emission factors based on the climate disaggregated default emission factors from IPCC 2019 refinements were implemented. The emission factor was changed from 0.02 and 0.01 to 0.00588 kg N_2O-N/kg N for cattle and 0.003 kg N_2O-N/kg N for the other grazing animals.

N-factor for reindeer was also updated in the 2024 submission. The IPCC 2019 refinement Equation 10.30 and Nex rate from Table 10.19 was used to estimate the factor. In Norway the average animal mass for these animals is 64 kg (Landbruksdirektoratet, “Ressursregnskap for reindriftsnæring” and expert opinion, Statistics Norway). Since reindeer in Norway only live on pastures the change in emission is referred to in 3D grazing and not in 3B.

[56] Christian Mohr, NIBIO, personal communication 25.09.2023.

These changes led to 70% lower N_2O emissions for the time series compared to former submission.

10.1.1.3.10 3Da4 N_2O from crop residues

For the emission of N_2O from crop residues there have been changes in the 2024 submission due to a new calculation model from IPCC 2019 refinements. The methodology for N_2O emissions from crop residues was updated for the 2024 submission, where it is now based on the updated equation detailed in the IPCC's 2019 refinement to the 2006 guidelines (described below) (IPCC 2019). Input data remains the same as in previous submissions. The new model is described in Carbon Limits (2023).

The emission factor for N_2O was also updated due to the 2019 refinements. The climate adjusted emission factor of 0.00597 kg N_2O-N/kg N applied has been used. This factor is based on the disaggregated IPCC default emission factors (IPCC 2019). When comparing old and new estimations N_2O emissions were 22% lower through the time series**.**

10.1.1.3.11 3Da6 N_2O from cultivation of organic soils

For 3Da6, N_2O 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 7% higher N_2O emissions on average throughout the time series compared to the 2023 submission.

10.1.1.3.12 3Db1 indirect N_2O emissions from Atmospheric deposition and leaching from managed soils

The IPCC 2019 refinements emission factors for N_2O were implemented both for atmospheric deposition and for leaching and run-off. The climate adjusted IPCC default emission factor of 0.01373 kg N_2O-N/(kg NH_3-N+NO_X-N volatilized) (IPCC 2019) is used to calculate indirect emissions of N_2O from volatilized NH_3 and NO_X. For atmospheric deposition the factor was changed from 0.01 to 0.01373 kg N_2O-N/kg N, which led to 50 per cent higher emissions for atmospheric deposition compared to former estimations. For leaching/ runoff the factor changed from 0.0075 to 0.011 kg N_2O-N/kg N. This led to 39% higher emissions from leaching as an average compared to former estimations.

10.1.1.4 Land use, Land use change and Forestry

All emissions related to the Norwegian National Forest Inventory (NFI) estimated areas are recalculated every year as well as for the 2024 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 1/5th of the NFI sample plots that are surveyed every year[57]. For any given year (after 1993) one fifth of the area estimates are therefore based on measured sample plots, and four fifths of the estimates are based on

[57] As of NIR2021, this method has been adapted slightly by performing the interpolation for each plot separately, and then aggregating to each NFI panel.

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.

Therefore, there will always be recalculation in the last few years of the time series. 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 in all land uses (CRF Tables 4.A-4.F). Non-CO_2 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_2O 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 2024 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). In addition, there were recalculations related to methodological changes.
The largest recalculations usually occur for the last four common years (2018 – 2021) mainly due to extrapolation updates. However, for this year's submission, large recalculations have occurred throughout the time series due to changes in activity data and methodologies:

- For the Tier 3 tree living biomass estimates, both the interpolation and extrapolation methodology for gains and losses have been revised. For gains the only change is going from using the last 10 years for extrapolating the trend in gains, to using the last 5 years. By reducing the time length from 10 to 5 years there is less influence of the historic trend on the extrapolation. This has previously been shown to result in large overshoots in both gains and losses. However, because of the NFI survey design, each plot is revisited after 5 years. So therefore, no trend can be observed, when attempting to use the trend for the last 5 years. As such, the last observations gains are simply projected forward resulting in a “flat line”. This same approach is also applied to the tree living biomass losses for natural mortality and other harvest (generally small-scale harvest not associated with clearcut harvest and thinning). For plots with clearcut harvest a new methodology has been applied for the interpolation and extrapolation. Remote sensing data product Global Forest Change (GFC) is for the first time used as surrogate data to detect whether clearcut harvests have occurred on NFI plots that have not yet been surveyed in the last 5 years. I.e. harvests have already occurred, but the plots will first be surveyed in the next upcoming five years. There is uncertainty in the GFC detection, resulting in both false positives and negatives detections. Future recalculations are therefore still expected for living biomass loss related to clearcut harvest, even if the method greatly reduces recalculations compared with linear trend extrapolation. And for all years in the timeseries, harvest statistics from Statistic Norway; NFI field-estimated harvest year; and remote sensing data from aerial and satellite images and GFC, are used to redistribute the loss over 5-years (time interval for each NFI observation) from clearcut harvest for each plot to the exact year of harvest. Previously only harvest statistics from Statistic Norway was used to distribute all tree living biomass loss determined for each NFI plots.

- Large recalculation for litter, dead wood and mineral soil estimates on forest land remaining forest land. Updates in the Tier 3 methodology and activity data have occurred in which natural mortality and other harvest input data to the Yasso07 model has changed.
- Grass living biomass is now accounted for on settlements with vegetation resulting in recalculations for land conversions to and from settlements.
- The following non-CO_2 emissions were also recalculated due to methodological updates (from the 2006 Guidelines to the 2019 Refinement): CRF Table 4(I) Direct N_2O emissions from cultivated soils, CRF Table 4(III) Direct N_2O emissions from N mineralization / immobilization and CRF Table 4(IV) Indirect N_2O emissions from cultivated soils. Total changes in emissions (including non-CO_2 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_2 uptake on forest land for the year 2021 was 4 071 kt CO_2 eq smaller in the 2024 submission compared to the 2023 submission. The difference in total GHG removals from the LULUCF sector were 3 755 kt CO_2 eq less in the 2024 NIR compared to the 2023 NIR submission for the recalculated year 2021 (Table 10-2).

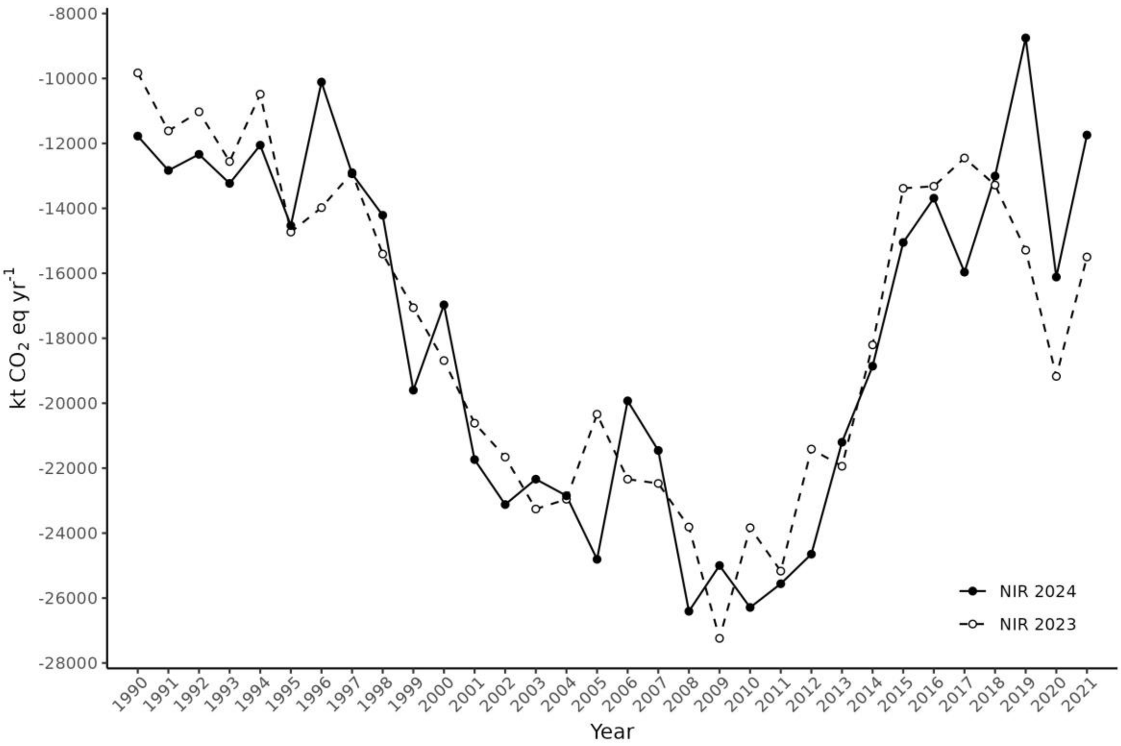


Figure 10.1: Recalculations illustrated for total emissions (kt CO_2 equivalents per year) estimated for the LULUCF sector in the 2024 submission compared to the 2023 submission.

Table 10-2: Recalculated GHG emissions (kt CO_2 equivalents yr^{-1}) for 2021 per land-use category in the LULUCF sector.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Land-use category	**NIR 2024**	**NIR 2023**	**difference**	**change description**
4.A Forest land	-16 125.5	-20 196.7	4 071.2	decreased net removals
4.B Cropland	2 520.9	2 336.9	184.0	increased net emissions
4.C Grassland	-136.8	188.7	-325.5	from net emission to net removals
4.D Wetlands	393.2	406.0	-12.8	decreased net emissions
4.E Settlements	1 892.4	1 989.6	-97.3	decreased net emissions
4.F Other land	0.0	0.0	0.0	no change
4.G HWP	-295.4	-229.3	-66.2	increased net removals

4(IV) Indirect N_2O	8.7	7.5	1.2	increased net emissions
Total sum	-11 742.6	-15 497.3	3 754.7	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 (2021) are described below.

10.1.1.4.1 Forest Land

10.1.1.4.1.1 4A1 Forest land remaining forest land

There has been a decrease in net removals of 4 022 kt CO_2 (from -19 268 kt CO_2 to -15 247 kt CO_2) for forest land remaining forest land.

Table 10-3: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for forest land remaining forest land. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
living biomass	-8 824.7	-14 654.5	5 829.9	decreased net removals
litter	-6 250.1	-4 785.2	-1 464.9	increased net removals
dead wood	-1 263.8	-967.6	-296.2	increased net removals
mineral soil	-145.5	-111.4	-34.1	increased net removals
organic soil	1 237.3	1 250.2	-12.9	decreased net emissions

- The large recalculation for tree living biomass have occurred due to updates in the interpolation and extrapolation methodology. The changes are especially large for losses (see detailed explanation above). The methodology is the same for all tree living biomass estimates. However, the largest changes are observed for forest land remaining forest land.
- Litter, dead wood, and mineral soil have been recalculated for the whole time-series. The main reason has been updates to the litter/dead wood input activity data used with Yasso07 model: Natural mortality and other harvest were previously estimated as a fraction of the calculated standing biomass. Now both natural mortality and other harvest are directly acquired from the NFI database for all years after 1993. Prior to 1994, including the back casting period (1951-1985),

natural mortality and other harvest are still estimated as a fraction of the standing biomass (observed or estimated).

- Drained organic soil emissions have been recalculated for the entire time-series. This is due to updates to the registrations in the NFI database.

10.1.1.4.1.2 4A2 Land converted to forest land

There has been a decrease in net removals of 52.6 kt CO_2 (from - 1 147 kt CO_2 to 1 094 kt CO_2) for land converted to forest land.

Table 10-4: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for land converted to forest land. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
living biomass	-152.2	-184.1	31.9	decreased net removals
litter	-556.9	-581.7	24.8	decreased net removals
dead wood	-383.3	-379.4	-3.8	increased net removals
mineral soil	-19.3	-19.0	-0.3	increased net removals
organic soil	17.2	17.2	0.0	no change

- 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. This is particularly the case for settlements converted to forest land in which area has been recalculated for the whole timeseries, and as a result net uptake and emissions also are recalculated.

10.1.1.4.2 Cropland

10.1.1.4.2.1 4B1 Cropland remaining cropland

There has been an increase in net emissions of 100.4 kt CO_2 (from 1 645 kt CO_2 to 1 746 kt CO_2) for cropland remaining cropland.

Table 10-5: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for cropland remaining cropland. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
organic soil	1803.9	1694.3	109.6	increased net emissions
mineral soil	-59.5	-50.8	-8.7	increased net removals
living biomass	1.6	2.2	-0.5	decreased net emissions
dead organic matter	0.0	0.0	0.0	no change

- For all sources changes occur in the last four years due to updated area extrapolation. However, reclassifications of the plots (whole and split) in the database occurs, which can cause recalculations for the whole timeseries. This is particularly the case for mineral and organic soil. By default, all soil is mineral unless observation from the National Soil Survey indicates differently. Since the National Soil Survey database has been updated, some land previously classified as mineral soil is now classified as organic soil. This has minimal implications for the emissions from mineral soil, but results in significant increase in emissions for the organic soil.

10.1.1.4.2.2 4B2 Land converted to cropland

There has been an increase in net emissions of 74.4 kt CO_2 (from 585.3 kt CO_2 to 659.7 kt CO_2) for land converted to cropland.

Table 10-6: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for land converted to cropland. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
dead organic matter	342.5	312.5	30.0	increased net emissions
living biomass	127.8	105.3	22.5	increased net emissions
organic soil	132.1	111.2	20.9	increased net emissions
mineral soil	57.4	56.3	1.0	increased net emissions

- Most of the recalculations are associated with forest land converted to cropland. Reclassifying plot previously assumed as harvested forest land, can be reclassified as deforestation when the plot is revisited and change in land use is observed. This is likely the explanation here, which results in an increase in area and the living biomass loss previously associated as harvest. And estimates calculated based on the area such as dead organic matter, mineral soil and drained organic soil will also have recalculations. There is also indication of reclassification of soil types in which mineral soil has been reduced and organic soil has increased, thereby increasing the overall net emissions.
- Settlements converted to cropland have also had minor changes. Some are related to land use reclassification, and some are related to the updated grass living biomass methodology for settlements with vegetation.

10.1.1.4.3 Grassland

10.1.1.4.3.1 4C1 Grassland remaining grassland

There has been an increase in net removals of -184 kt CO_2 (from -288.8 kt CO_2 to -472.8 kt CO_2) for grassland remaining grassland.

Table 10-7: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for grassland remaining grassland. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
living biomass	-571.3	-388.6	-182.7	increased net removals
mineral soil	26.8	28.0	-1.3	decreased net emissions
dead organic matter	0.0	0.0	0.0	no change
organic soil	71.7	71.7	0.0	no change

- The estimates of tree living biomass were updated for the whole time series due to changes in area estimates, and due to the new methodology for estimating living biomass, which is now a Tier 3 for Extensive Grasslands and a Tier2/Tier3 for Intensive Grasslands.

- Similarly mineral soils emissions were updated for the whole time series due to updated mineral area estimates in the database.

10.1.1.4.3.2 4C2 Land converted to grassland

There has been a decrease in net emissions of -142.2 kt CO_2 (from 461.4 kt CO_2 to 319.3 kt CO_2) for land converted to grassland.

Table 10-8: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for land converted to grassland. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
living biomass	9.7	173.8	-164.1	decreased net emissions
dead organic matter	287.5	266.2	21.2	increased net emissions
mineral soil	-9.4	-10.1	0.7	decreased net removals
organic soil	31.5	31.5	0.0	no change

- Living biomass, dead organic matter, and mineral soil estimates were recalculated mainly due to updated extrapolation. The majority of the recalculation comes from forest land to grassland.
- Settlements converted to grassland have also had minor changes related to the updated grass living biomass methodology for settlements with vegetation.

10.1.1.4.4 Wetlands

10.1.1.4.4.1 4D1 Wetlands remaining wetlands

There has been an increase in net emissions of 19.7 kt CO_2 (from 235.1 kt CO_2 to 254.7 kt CO_2) for wetlands remaining wetlands.

Table 10-9: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for wetlands remaining wetlands. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
living biomass	-64.7	-76.4	11.7	decreased net removals
organic soil	319.4	311.5	7.9	increased net emissions

- Overall, there are some land use reclassifications for other wetlands remaining other wetlands. However, a major change is the revised Tier 3 methodology for living biomass loss and interpolation and extrapolation. There is likely no or very little harvest on the other wetlands remaining other wetlands. Most losses are likely associated with natural mortality. However, previously annual redistribution of the interpolated-extrapolated tree living biomass losses used harvest statistics from Statistics Norway. For the current submission only clearcut harvest tree living biomass losses uses surrogate data for redistribution. Natural mortality uses interpolated-extrapolated tree living biomass losses directly. For this reason, small differences will be observed throughout the timeseries (see detailed explanation above in section 10.1.1.4).
- In addition, updated extrapolation results in recalculations for the last four common years of other wetlands remaining other wetlands.
- Activity data for peat extraction remaining peat extraction is based on surveys in which industries provide the quantity of peat extracted for each year. However, there is ambiguity in whether the volume numbers they provide are “raw” volume or “dry” volume. After further investigation into what volume is reported it seems that the producers did not understand the survey question and that volume difference between “raw” and “dry” peat was negligible or minor at best. For this reason, the “raw” to “dry" volume correction applied to the activity data has been removed for 2008 to 2021, resulting in the recalculation in net emissions observed for organic soil.

10.1.1.4.4.2 4D2 Land converted to wetlands

There has been a decrease in net emissions of -32.4 kt CO_2 (from 129.4 kt CO_2 to 97.0 kt CO_2) for land converted to wetlands.

Table 10-10: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for land converted to wetlands. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
dead organic matter	60.9	82.2	-21.3	decreased net emissions
living biomass	27.5	38.7	-11.1	decreased net emissions
mineral soil	0.0	0.0	0.0	no change
organic soil	8.6	8.6	0.0	no change

- The recalculations for all estimates were due to updated extrapolation for the last four common years.

10.1.1.4.5 Settlements

10.1.1.4.5.1 4E1 Settlements remaining settlements

There has been a decrease in net emissions of -0.4 kt CO_2 (from 172.5 kt CO_2 to 172.1 kt CO_2) for settlements remaining settlements.

Table 10-11: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021for each carbon pool for settlements remaining settlements. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
organic soil	172.1	172.5	-0.4	decreased net emissions
living biomass	0	0	0	no change
dead organic matter	0	0	0	no change
mineral soil	0	0	0	no change

- Recalculations for organic soils were due to database updates.

10.1.1.4.5.2 4E2 Land converted to settlements

There has been a decrease in net emissions of -97.9 kt CO_2 (from 1 753.0 kt CO_2 to 1 655.2 kt CO_2) for land converted to settlements.

Table 10-12: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each carbon pool for land converted to settlements. Ordered by descending absolute difference.

	Emissions for 2021(kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
living biomass	497.9	596.6	-98.7	decreased net emissions
mineral soil	116.7	70.2	46.5	increased net emissions
dead organic matter	837.6	874.8	-37.2	decreased net emissions
organic soil	202.9	211.5	-8.6	decreased net emissions

- Tree living biomass emission estimates had the largest changes for lands converted to settlements. The main reason for the large change is due to updated Tier 3 tree living biomass methodology which impacts the net emission for Forest land converted to settlements (see section 10.1.1.4). In addition, the updated methodology to include grass biomass for settlements means that there is also estimated grass living biomass uptake for land use transitions to settlements with vegetation. For the transition from grassland to settlements the loss is reduced as change from grassland to vegetated settlement now results in less living biomass loss.
- All land use conversions to settlements have some recalculations due to land use and soil type reclassification in the database. This has resulted in both whole and partial recalculation in net emission for the timeseries. Additionally, the last four common years are recalculated due to the updated extrapolation.

10.1.1.4.6 Other Land

10.1.1.4.6.1 4F1 Other land remaining other land

There have been no, or only minor recalculations performed for this source category this year.

10.1.1.4.6.2 4F2 Land converted to other land

There have been no, or only minor recalculations performed for this source category this year.

10.1.1.4.7 Harvested wood products

There has been an increase in net removals of -66.2 kt CO_2 (from -229.3 kt CO_2 to -295.4 kt CO_2) for HWP.

Table 10-13: Recalculated CO_2 emissions (kt CO_2 yr^{-1}) for 2021 for each HWP. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Carbon pool	**NIR 2024**	**NIR 2023**	**difference**	**change description**
Domestic Paper and paperboard	-8.4	57.7	-66.2	from net emission to net removals
Domestic Sawnwood	-92.4	-92.4	0.0	no change
Domestic Wood panels	102.4	102.4	0.0	no change
Export Sawnwood	-409.4	-409.4	0.0	no change
Export Wood panels	-92.3	-92.3	0.0	no change
Export Paper and paperboard	204.7	204.7	0.0	no change

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 reason for the recalculation in domestic paper and paperboard is the following: The 'outflow' (losses) is calculated as 'inflow' (activity data) minus 'stock-change. In NIR 2022 for the year 2020, the ‘stock change’ reached a historically high value (140 992 metric t, 54 423 t C), resulting in a negative value for 'outflows' (losses): -13 194 metric t, -5 093 t C. In NIR 2023 the activity data was updated from the FAOSTAT database, and the 'outflows' (losses) increased even more: -55 331 metric t, -21 358 t C). However, negative values cannot be used in the CRF input table. To solve this, we used 0 as value for the outflow in NIR 2022. But after further discussions after the review comment we have changed the approach slightly: We have considered the outflow to be 0, and the absolute value has been reported as an inflow (negative losses are equal to gains) so that the totals match.

10.1.1.4.8 4 (I) Direct N_2O emission from managed soils

There has been a decrease in net emissions of -3.6 kt CO_2 eq (from *11.7* kt CO_2 eq to 8.1 kt CO_2 eq) for N_2O from fertilized soils.

Table 10-14: Recalculated non-CO_2 GHG emissions (kt CO_2 eq yr^{-1}) for 2021 for fertilized land uses. Ordered by descending absolute difference.

			Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Land-use change	**source**	**GHG**	**NIR 2024**	**NIR 2023**	**difference**	**change description**
Settlements remaining Settlements	Organic N fertilizers	N_2O	3.7	6.2	-2.5	decreased net emissions
Forest land remaining forest land	Inorganic N fertilizers	N_2O	4.4	5.5	-1.1	decreased net emissions

- Recalculations are due to the update in methodology according to IPCC (2019). Emission factors were disaggregated and applied to specific climate zones, resulting in recalculations for the entire time series.

10.1.1.4.9 4 (II) Emissions and removal from drainage of organic soils

There has been an increase in net emissions of 1.7 kt CO_2 eq (from 420.2 kt CO_2 eq to 421.9 kt CO_2 eq) for drained organic soil non-CO_2 GHG.

Table 10-15: Recalculated non-CO_2 GHG emissions (kt CO_2 eq yr^{-1}) for 2021 for drained organic soil. Ordered by descending absolute difference.

		Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Land use	**GHG**	**NIR 2024**	**NIR 2023**	**difference**	**change description**
Cropland	CH_4	109.0	101.7	7.3	increased net emissions
Settlements	N_2O	19.5	23.0	-3.5	decreased net emissions
Forest land	N_2O	153.4	155.0	-1.6	decreased net emissions
Forest land	CH_4	56.6	57.2	-0.6	decreased net emissions
Settlements	CH_4	28.0	28.0	0.1	increased net emissions
Wetlands	N_2O	31.4	31.4	0.0	no change
Grassland	CH_4	13.9	13.9	0.0	no change
Wetlands	CH_4	10.1	10.1	0.0	no change

- All observed changes were contributed by updates in the NFI database and extrapolation.

10.1.1.4.10 4(III) Direct N_2O emissions from N mineralization and immobilisation

There has been an increase in net emissions of 9.7 kt CO_2 eq (from 13.5 kt CO_2 eq to 23.2 kt CO_2 eq) for direct N_2O emissions.

Table 10-16: Recalculated direct N_2O emissions (kt CO_2 eq yr^{-1}) from N mineralization/immobilization for 2021. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Land-use change	**NIR 2024**	**NIR 2023**	**difference**	**change description**
Lands converted to settlements	13.9	6.9	7.0	increased net emissions
Lands converted to cropland	6.1	4.3	1.8	increased net emissions
Grasslands remaining grasslands	2.8	2.1	0.7	increased net emissions
Forest land remaining forest land	0.2	0.0	0.2	from net zero to net emission
Lands converted to forest land	0.2	0.2	0.0	increased net emissions

- Observed changes were mainly due to updates of the NFI area and extrapolation.
- Recalculations are also due to update in methodology according to IPCC (2019). Emission factors were disaggregated and applied to specific climate zones, resulting in recalculations for the entire time series.

10.1.1.4.11 4(IV) Indirect N_2O emissions from managed soils

There has been an increase in net emissions of 1.2 kt CO_2 eq (from 7.5 kt CO_2 eq to 8.7 kt CO_2 eq) for indirect N_2O emissions.

Table 10-17: Recalculated indirect N_2O emissions (kt CO_2 eq yr^{-1}) for 2021. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
Source	**NIR 2024**	**NIR 2023**	**difference**	**change description**
Nitrogen leaching and run-off	6.7	5.7	1.0	increased net emissions
Atmospheric deposition	2.0	1.8	0.2	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_2O emissions.
- Recalculations are also due to update in methodology according to IPCC (2019). Emission factors were disaggregated and applied to specific climate zones, resulting in recalculations for the entire time series.

10.1.1.4.12 4(V) Biomass burning

There have been no changes for forest land wildfires.

Table 10-18: Recalculated non-CO_2 GHG emissions (kt CO_2 eq yr^{-1}) for 2021 forest land wildfires. Ordered by descending absolute difference.

	Emissions for 2021 (kt CO_2 equivalents yr^{-1})			
GHG	**NIR 2024**	**NIR 2023**	**difference**	**change description**
N_2O	0.3	0.3	0.0	no change
CH_4	0.6	0.6	0.0	no change

10.1.1.5 Waste

10.1.1.5.1 5A1A Anaerobic managed waste disposal sites

Revised activity data. Recovered amounts of methane are updated in the period 2017-2021 due to new information. The emissions are reduced by 1.4% in 2019 and by 0.1% in 2017. There are only minor changes in other years.

10.1.1.5.2 5B1 Composting

5B1a: New data source. The activity data are updated in 2017-2021 due to access to a new data source. The emissions are reduced for all components in the whole period.
5B1b: Revised activity data. The activity data is updated in 2021 due to updated information on the share of domestic waste.

10.1.1.5.3 5B2 Anaerobic Digestion at Biogas Facilities

5B2a: New data source. The activity data are updated in 2017-2021 due to access to a new data source. The emissions are increased throughout the whole period.

10.1.1.5.4 5C1 Waste Incineration

5C11a: Revised activity data. The activity data is updated in the period 2010-2021 due to updated amounts of flared biogas in the energy balance.
5C11b: Revised activity data. Updated information from a biogas production facility has led to a reduction of emissions from 2019 to 2021.

5C12a: Updated emission factor and reallocation.

- The emission factor for CO_2 is updated for the period 2010-2021 based on a national analysis (MEPEX 2020). The new emission factor led to higher emissions of CO_2. The previous emission factor states back to investigations made in 2009 while the new data are gathered for 2014-2018. The emission factor is hence calculated by linear interpolation in 2010-2013 and it is kept at the 2018-level in the years after 2018.
- There has been a reallocation between 5C12A and 1A1Aiiii. The intent is to separate emissions from waste incinerated with and without energy recovery. The reallocation has led to updated timeseries for emissions of CO_2 and N_2O.

10.1.1.5.5 5D1 Domestic Wastewater

- Correction of error. The emissions of N_2O have been reduced throughout the time series, due to the removal of data that was added twice in the calculation.
- Correction of error. An error in the activity data in 2011 has been corrected. The updated led to a reduction in the emissions of CH_4 by 22.7% compared to the 2023 submission.

10.1.1.5.6 5D2 Industrial Wastewater

- Revised activity data. Updated information on activity data in 2021 in the food processing industries led to a minor reduction of CH_4 emissions (-0.6%).

10.1.1.6 Indirect CO_2 in CRF tables 2,6 and 10

Reallocation. The indirect emissions of CO_2 from emissions of NMVOC in 2D3 are now reported in the IPPU sector. This is to ensure the highest possible consistency with the guidance provided in the IPCC 2006 Guidelines related to the reporting of “Non-energy products from fuels and solvent use” and the description of reporting categories under 2D in Volume 1, chapter 8, table 8.2 of the 2006 IPCC Guidelines.

Recalculation of emission factors. Several emission factors for indirect CO_2 from NMVOC has been updated since the previous submission, resulting in increased indirect CO_2 emissions.

- The standard EF is updated from 2.2 to 3.11666667
- Sources with new specific emission factor of 3
    - 1B2a4 refinery
    - 1B2b6 gas terminal
    - 1b2bc venting
    - 2B8b ethylene/VCM
    - 2B8g plastic
- Implications for emission and removal levels

The overall impact of recalculations without the LULUCF-sector, was minor, adding up to a reduction of 0.08% (42 ktonnes CO_2 equivalents) in 1990 and an increase of 0.20% (96 ktonnes) in 2021. See Figure 10.2: and Table 10-19.

Recalculations in the LULUCF sector 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 5.4% lower (about 1 988 ktonnes CO_2 equivalents) than in the previous submission and about 11% higher (3 850 ktonnes) in 2021. See chapter 10.1.1.4 for more information on the recalculations in the LULUCF-sector.

10.2 Implications for emission and removal levels

The overall impact of recalculations without the LULUCF-sector, was minor, adding up to a reduction of 0.08% (42 ktonnes CO_2 equivalents) in 1990 and an increase of 0.20% (96 ktonnes) in 2021. See Figure 10.2: and Table 10-19.

Recalculations in the LULUCF sector 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 5.4% lower (about 1 988 ktonnes CO_2 equivalents) than in the previous submission and about 11% higher (3 850 ktonnes) in 2021. See chapter 10.1.1.4 for more information on the recalculations in the LULUCF-sector.

Table 10-19 shows the effects of recalculations on the total emission figures for CO_2 equivalents for the period 1990-2021.

Table 10-19: Implications of recalculations for total emissions (including and excluding LULUCF). 1000 tonnes CO_2 equivalents.

	Without LULUCF			With LULUCF		
Year	**Previous submission**	**Latest submission**	**Difference due to recalcutions**	**Previous submission**	**Latest submission**	**Difference due to recalcutions**
1990	51 305	51 263	-42	41 477	39 489	-1 988
1991	48 955	48 908	-48	37 339	36 076	-1 264
1992	47 419	47 376	-43	36 393	35 040	-1 353
1993	49 378	49 309	-70	36 821	36 077	-744
1994	51 330	51 255	-75	40 847	39 201	-1 646
1995	51 717	51 670	-47	36 987	37 139	152
1996	54 617	54 562	-54	40 640	44 451	3 812
1997	54 606	54 539	-68	41 705	41 603	-102
1998	54 672	54 608	-64	39 266	40 396	1 130

1999	55 683	55 611	-72	38 623	36 012	-2 612
2000	55 070	55 003	-68	36 384	38 031	1 647
2001	56 339	56 248	-91	35 724	34 511	-1 213
2002	55 078	54 935	-142	33 419	31 815	-1 604
2003	55 717	55 543	-174	32 459	33 203	745
2004	56 101	55 908	-193	33 144	33 059	-85
2005	55 003	54 787	-216	34 663	29 980	-4 683
2006	55 015	54 760	-255	32 676	34 832	2 156
2007	56 712	56 450	-263	34 242	34 994	752
2008	55 232	54 927	-305	31 420	28 520	-2 900
2009	52 855	52 436	-419	25 614	27 438	1 824
2010	55 233	54 732	-501	31 399	28 442	-2 956
2011	54 289	53 744	-545	29 119	28 184	-935
2012	53 671	53 166	-505	32 259	28 519	-3 740
2013	53 916	53 407	-510	31 976	32 204	229
2014	54 246	53 806	-440	36 040	34 946	-1 094
2015	54 691	54 324	-367	41 308	39 272	-2 036
2016	53 765	53 451	-314	40 446	39 764	-681
2017	52 981	52 745	-236	40 532	36 780	-3 751
2018	53 001	52 843	-157	39 719	39 839	120
2019	51 219	51 082	-136	35 930	42 329	6 400
2020	49 498	49 406	-92	30 325	33 291	2 966

Table 10-20 to Table 10-25 show the effects of recalculations on the total emission figures for CO_2, CH_4, N_2O, HFCs, PFCs and SF6.

Table 10-20: Implications of recalculations for CO_2 emissions (kt, including and excluding LULUCF).

	Excluding LULUCF			**Including LULUCF**		
Year	Previous submission	Latest submission	Difference due to recalcutions	Previous submission	Latest submission	Difference due to recalcutions
1990	35 015	35 003	-12	24 784	22 815	-1 969
1991	33 467	33 458	-9	21 445	20 210	-1 236
1992	34 397	34 394	-3	22 964	21 640	-1 324
1993	35 945	35 938	-7	22 983	22 292	-691
1994	37 860	37 853	-7	26 972	25 384	-1 588
1995	38 467	38 458	-9	23 331	23 512	180
1996	41 533	41 524	-9	27 149	30 995	3 846
1997	41 639	41 625	-15	28 326	28 267	-59
1998	41 828	41 818	-10	26 006	27 180	1 174
1999	42 597	42 591	-6	25 119	22 565	-2 555
2000	42 117	42 110	-7	23 012	24 710	1 698
2001	43 503	43 498	-5	22 468	21 332	-1 136
2002	42 564	42 553	-11	20 483	19 001	-1 482
2003	43 915	43 900	-15	20 233	21 128	895
2004	44 252	44 236	-15	20 873	20 957	84
2005	43 280	43 263	-18	22 517	18 023	-4 494
2006	43 864	43 842	-22	21 097	23 477	2 380
2007	45 618	45 588	-29	22 723	23 699	975
2008	44 708	44 675	-33	20 463	17 826	-2 637
2009	43 116	43 081	-35	15 444	17 643	2 198
2010	45 662	45 621	-41	21 392	18 885	-2 507
2011	44 790	44 747	-43	19 185	18 740	-444
2012	44 270	44 228	-43	22 421	19 132	-3 289
2013	44 551	44 516	-35	22 173	22 866	693
2014	44 981	44 958	-23	26 339	25 650	-688
2015	45 522	45 501	-21	31 702	30 001	-1 701
2016	44 681	44 687	6	30 908	30 539	-369
2017	44 129	44 165	36	31 226	27 739	-3 487
2018	44 278	44 405	127	30 544	30 939	395
2019	42 706	42 793	88	26 969	33 582	6 614
2020	41 173	41 210	37	21 551	24 636	3 085
2021	40 920	41 028	108	24 969	28 823	3 854

Table 10-21: Implications of recalculations for CH_4 emissions (including LULUCF).

	CH_4 emissions (kt)			CH_4 emissions (kt CO_2 eq.)		
Year	Previous submission	Latest submission	Difference due to recalcutions	Previous submission	Latest submission	Difference due to recalcutions
1990	256	249	-7	7 171	6 979	-192
1991	251	243	-7	7 018	6 815	-204
1992	254	247	-7	7 114	6 913	-201
1993	260	252	-8	7 276	7 053	-223
1994	263	255	-8	7 373	7 154	-219
1995	264	256	-7	7 379	7 181	-198
1996	264	256	-7	7 387	7 177	-210
1997	265	257	-8	7 414	7 195	-220
1998	256	248	-8	7 159	6 941	-218
1999	254	246	-7	7 105	6 896	-209
2000	254	247	-8	7 116	6 903	-213
2001	254	246	-8	7 105	6 884	-221
2002	248	239	-10	6 956	6 690	-266
2003	247	237	-11	6 925	6 631	-294
2004	243	232	-11	6 802	6 497	-305
2005	237	224	-12	6 632	6 285	-347
2006	231	219	-12	6 472	6 131	-341
2007	234	223	-12	6 565	6 232	-333
2008	229	216	-13	6 400	6 036	-364
2009	230	215	-15	6 441	6 025	-416
2010	230	214	-17	6 450	5 982	-468
2011	225	206	-19	6 312	5 772	-540
2012	222	204	-17	6 208	5 723	-484
2013	218	202	-16	6 118	5 657	-461
2014	216	200	-16	6 057	5 612	-445
2015	216	200	-16	6 055	5 604	-451
2016	213	199	-14	5 959	5 573	-386
2017	207	196	-11	5 801	5 487	-314
2018	204	193	-11	5 714	5 407	-308
2019	197	185	-12	5 510	5 184	-325
2020	196	186	-11	5 498	5 201	-297
2021	195	185	-10	5 468	5 188	-280

Table 10-22: Implications of recalculations for N_2O emissions (including LULUCF).

	N_2O emissions (kt)			N_2O emissions (kt CO_2 eq.)		
Year	Previous submission	Latest submission	Difference due to recalculations	Previous submission	Latest submission	Difference due to recalculations
1990	15	15	1	3 858	4 031	173
1991	14	15	1	3 724	3 900	176
1992	12	13	1	3 250	3 421	171
1993	13	14	1	3 425	3 595	170
1994	13	14	1	3 485	3 645	160
1995	13	14	1	3 509	3 678	169
1996	13	14	1	3 523	3 697	174
1997	13	14	1	3 517	3 692	175
1998	14	14	1	3 602	3 774	172
1999	14	15	1	3 792	3 941	149
2000	14	14	1	3 617	3 775	158
2001	13	14	1	3 546	3 686	140
2002	14	15	1	3 765	3 907	141
2003	14	14	1	3 634	3 783	148
2004	14	15	1	3 759	3 915	155
2005	14	15	1	3 823	3 986	164
2006	13	14	1	3 531	3 688	158
2007	13	13	1	3 369	3 541	172
2008	11	12	1	2 979	3 140	161
2009	9	10	0	2 492	2 623	131
2010	9	10	0	2 416	2 529	113
2011	9	10	1	2 407	2 558	150
2012	9	10	1	2 416	2 560	144
2013	9	10	1	2 397	2 536	139
2014	9	10	1	2 405	2 559	154
2015	9	10	1	2 440	2 594	154
2016	9	10	1	2 398	2 543	145
2017	9	9	0	2 357	2 485	129
2018	9	9	1	2 331	2 470	139
2019	9	9	1	2 349	2 504	155
2020	9	9	1	2 305	2 457	152
2021	9	9	1	2 311	2 464	153

Table 10-23: Implications of recalculations for HFC emissions (including LULUCF).

	HFC emissions (kt CO_2 eq.)		
Year	**Previous submission**	**Latest submission**	**Difference due to recalculations**
1990	0	0	0
1991	1	1	0
1992	3	3	0
1993	33	33	0
1994	50	50	0
1995	92	92	1
1996	123	124	1
1997	186	188	2
1998	246	248	2
1999	310	312	3
2000	357	360	3
2001	452	456	4
2002	490	493	3
2003	500	495	-5
2004	527	508	-19
2005	528	522	-6
2006	596	554	-41
2007	657	594	-63
2008	709	650	-59
2009	784	696	-88
2010	855	761	-94
2011	923	823	-101
2012	980	869	-110
2013	1 068	926	-142
2014	1 028	914	-114
2015	910	872	-38
2016	951	879	-72
2017	973	894	-79
2018	940	834	-106
2019	874	831	-44
2020	750	776	26
2021	628	743	115

Table 10-24: Implications of recalculations for PFC emissions (in CO_2 eq. including LULUCF).

	PFC emissions (kt CO_2 eq.)		
Year	Previous submission	Latest submission	Difference due to recalculations
1990	3 500	3 500	0
1991	3 106	3 106	0
1992	2 369	2 369	0
1993	2 379	2 379	0
1994	2 104	2 104	0
1995	2 079	2 079	0
1996	1 893	1 893	0
1997	1 691	1 691	0
1998	1 538	1 538	0
1999	1 437	1 437	0
2000	1 364	1 364	0
2001	1 376	1 376	0
2002	1 490	1 490	0
2003	945	945	0
2004	914	914	0
2005	858	858	0
2006	772	772	0
2007	855	855	0
2008	805	805	0
2009	394	394	0
2010	214	214	0
2011	236	236	0
2012	180	180	0
2013	163	163	0
2014	161	161	0
2015	132	132	0
2016	167	167	0
2017	118	118	0
2018	133	133	0
2019	157	157	0
2020	145	145	0
2021	223	223	0

Table 10-25: Implications of recalculations for SF6 emissions (in CO_2 eq. including LULUCF).

	SF6 emissions (kt CO_2 eq.)		
Year	**Previous submission**	**Latest submission**	**Difference due to recalculations**
1990	2 163	2 163	0
1991	2 044	2 044	0
1992	693	693	0
1993	725	725	0
1994	863	863	0
1995	598	598	0
1996	564	564	0
1997	570	570	0
1998	714	714	0
1999	859	859	0
2000	919	919	0
2001	778	778	0
2002	234	234	0
2003	222	222	0
2004	269	269	0
2005	306	306	0
2006	209	209	0
2007	73	73	0
2008	63	63	0
2009	58	58	0
2010	71	70	0
2011	55	55	0
2012	54	54	0
2013	57	57	0
2014	50	50	0
2015	70	69	0
2016	63	63	0
2017	58	58	0
2018	56	55	0
2019	70	70	0
2020	76	76	0
2021	62	72	9

Table 10-26 to Table 10-30 show the effects of recalculations for CO_2 equivalents per sector.

Table 10-26: Implications of recalculations for emissions in the energy sector (in CO_2 eq.).

Year	Previous submission	Latest submission	Difference due to recalculations
1990	28 397	28 332	-66
1991	27 321	27 239	-81
1992	28 373	28 287	-85
1993	29 479	29 383	-96
1994	31 065	30 975	-90
1995	31 477	31 408	-69
1996	34 536	34 453	-83
1997	34 301	34 198	-103
1998	34 260	34 163	-97
1999	35 213	35 135	-79
2000	34 304	34 214	-90
2001	36 036	35 935	-101
2002	35 895	35 748	-147
2003	37 165	36 996	-170
2004	36 945	36 770	-175
2005	36 541	36 323	-218
2006	37 402	37 183	-219
2007	39 142	38 930	-212
2008	37 888	37 642	-247
2009	37 917	37 621	-296
2010	39 515	39 161	-354
2011	38 411	38 029	-382
2012	37 973	37 599	-374
2013	38 043	37 695	-348
2014	38 289	37 949	-340
2015	38 750	38 414	-336
2016	37 898	37 650	-248
2017	37 233	37 069	-164
2018	37 262	37 168	-94
2019	35 691	35 560	-131
2020	34 023	33 849	-174
2021	33 741	33 642	-99

Table 10-27: Implications of recalculations for emissions in the IPPU sector (in CO_2 eq.).

Year	Previous submission	Latest submission	Difference due to recalculations
1990	14 697	14 815	117
1991	13 581	13 684	103
1992	10 948	11 054	106
1993	11 731	11 838	107
1994	12 052	12 166	114
1995	11 914	12 026	112
1996	11 803	11 921	118
1997	12 117	12 232	115
1998	12 423	12 538	115
1999	12 481	12 595	114
2000	12 777	12 887	110
2001	12 380	12 493	112
2002	11 522	11 636	114
2003	10 953	11 060	107
2004	11 687	11 783	96
2005	11 229	11 327	98
2006	10 532	10 587	55
2007	10 521	10 555	34
2008	10 475	10 509	34
2009	8 152	8 138	-14
2010	8 890	8 887	-3
2011	9 024	9 017	-8
2012	8 952	8 937	-14
2013	9 087	9 047	-40
2014	9 084	9 084	0
2015	9 098	9 169	71
2016	9 039	9 082	43
2017	9 023	9 066	42
2018	9 081	9 087	7
2019	9 064	9 110	46
2020	9 001	9 149	148
2021	9 015	9 279	265

Table 10-28: Implications of recalculations for emissions in the agriculture sector (in CO_2 eq).

Year	Previous submission	Latest submission	Difference due to recalculations
1990	4 947	4 979	33
1991	4 878	4 917	39
1992	4 848	4 890	42
1993	4 841	4 871	29
1994	4 851	4 872	22
1995	4 889	4 919	31
1996	4 924	4 959	35
1997	4 863	4 910	48
1998	4 855	4 896	41
1999	4 882	4 891	9
2000	4 715	4 741	25
2001	4 667	4 677	10
2002	4 649	4 661	12
2003	4 727	4 742	15
2004	4 688	4 704	16
2005	4 697	4 723	26
2006	4 606	4 634	28
2007	4 594	4 637	43
2008	4 579	4 614	35
2009	4 571	4 576	5
2010	4 494	4 487	-7
2011	4 453	4 493	40
2012	4 471	4 503	31
2013	4 523	4 547	24
2014	4 594	4 647	53
2015	4 662	4 705	43
2016	4 719	4 748	28
2017	4 695	4 723	28
2018	4 673	4 736	63
2019	4 631	4 683	52
2020	4 649	4 698	50
2021	4 702	4 750	48

Table 10-29: Implications of recalculations for emissions in the LULUCF sector (in CO_2 eq).

Year	Previous submission	Latest submission	Difference due to recalculations
1990	-9 829	-11 775	-1 946
1991	-11 616	-12 832	-1 216
1992	-11 026	-12 337	-1 310
1993	-12 557	-13 232	-675
1994	-10 483	-12 054	-1 571
1995	-14 730	-14 531	199
1996	-13 977	-10 111	3 866
1997	-12 901	-12 936	-35
1998	-15 406	-14 212	1 193
1999	-17 059	-19 599	-2 540
2000	-18 687	-16 972	1 715
2001	-20 615	-21 736	-1 121
2002	-21 659	-23 120	-1 462
2003	-23 259	-22 340	919
2004	-22 957	-22 848	109
2005	-20 340	-24 807	-4 468
2006	-22 339	-19 928	2 411
2007	-22 470	-21 456	1 015
2008	-23 812	-26 407	-2 595
2009	-27 241	-24 998	2 243
2010	-23 834	-26 290	-2 455
2011	-25 170	-25 560	-390
2012	-21 412	-24 648	-3 235
2013	-21 941	-21 202	739
2014	-18 206	-18 860	-654
2015	-13 382	-15 051	-1 669
2016	-13 320	-13 687	-367
2017	-12 449	-15 964	-3 515
2018	-13 282	-13 005	277
2019	-15 289	-8 753	6 536
2020	-19 173	-16 115	3 058
2021	-15 497	-11 743	3 755

Table 10-30: Implications of recalculations for emissions in the waste sector (in CO_2 eq.).

Year	Previous submission	Latest submission	Difference due to recalculations
1990	2 671	2 671	0
1991	2 560	2 560	0
1992	2 539	2 539	1
1993	2 548	2 548	0
1994	2 535	2 531	-3
1995	2 555	2 551	-4
1996	2 455	2 454	-1
1997	2 413	2 411	-2
1998	2 227	2 225	-2
1999	2 165	2 163	-2
2000	2 278	2 276	-2
2001	2 215	2 213	-2
2002	2 107	2 105	-2
2003	2 102	2 100	-2
2004	2 108	2 105	-3
2005	2 005	2 002	-3
2006	2 029	2 026	-3
2007	2 016	2 012	-4
2008	1 939	1 935	-3
2009	1 901	1 898	-3
2010	2 026	2 021	-5
2011	2 112	2 052	-60
2012	1 985	1 982	-3
2013	1 962	1 961	-2
2014	1 940	1 941	1
2015	1 853	1 853	1
2016	1 791	1 796	5
2017	1 727	1 720	-8
2018	1 687	1 680	-8
2019	1 573	1 567	-6
2020	1 541	1 555	14
2021	1 445	1 454	10

10.3 Implications for emission and removal trends, including time-series consistency

The national emissions without LULUCF decreased by 3.3% between base year (1990) and 2021. The equivalent figure was 3.6% in the previous submission. When including LULUCF in the national totals, the trend between 1990 and 2021 changes from -18% to -4% in the latest submission. See

Table 10-31.

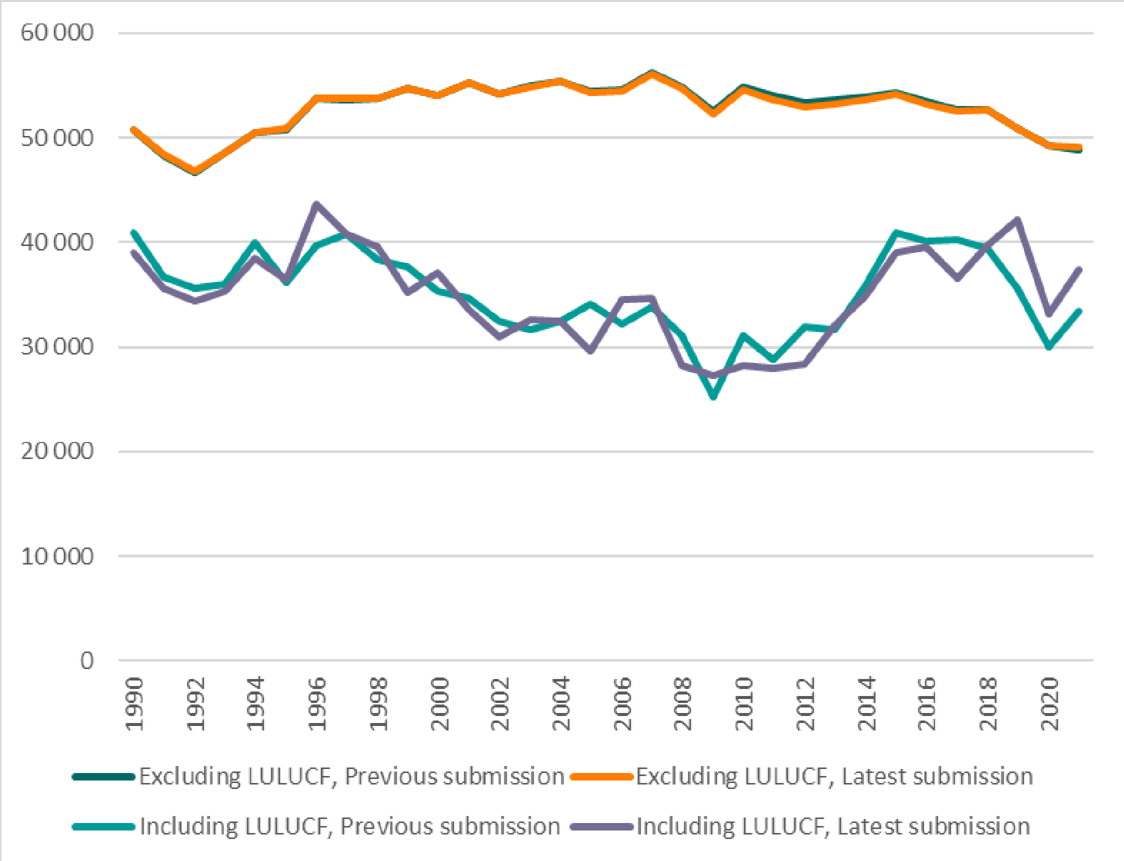


Figure 10.2: Total emissions with and without LULUCF. Previous and latest submission. 1000 tonnes CO_2 equivalents.

Table 10-31: Total emissions with and without LULUCF for 1990 and 2021. Previous and latest submission. 1000 tonnes CO_2 equivalents and per cent.

	Without LULUCF			With LULUCF		
	Previous submission	Latest submission	Difference due to recalculations	Previous submission	Latest submission	Difference due to recalculations
Emissions 1990	50 712	50 797	84	40 884	39 022	-1 862
Emissions 2020	48 902	49 125	223	33 405	37 382	3 978
Trend ktonnes	-1 810	-1 672	139	-7 479	-1 640	5 839
Trend per cent	-3,6	-3,3	0,3	-18	-4	14

Figure 10.3: Difference in total emissions for 2021 per gas, excluding LULUCF, between latest and previous submission. 1000 tonnes CO_2 equivalents.

10.4 Areas of improvement and/or capacity building 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 largely complete and transparent.

The status of implementation of the recommendations given in the most recently published UNFCCC review report is given in Table 10-32.

Table 10-32: The status of implementation of the recommendations given in the most recently published UNFCCC review report.

CRF category / issue	Review recommendation	Review report* and paragraph	MS response / status of implementation	Chapter/section in the NIR
General, recalculations	The ERT recommends that the Party explain in the NIR how it determines whether recalculations are significant enough to be documented in the NIR or should be considered as small differences in accordance with paragraph 45 of the UNFCCC Annex I inventory reporting guidelines and thus not documented.	ARR/2022 G.11	Addressed. Documented in NIR chapter 10.	NIR chapter 10.1
General, indirect emissions	The ERT recommends that Norway report in the CRF tables and in the NIR the national totals with and without indirect CO2 in line with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines, making relevant changes to its sectoral level reporting as necessary.	ARR/2022 G.1 (ARR/2020 G.13)	Addressed. Indirect CO2-emissions have been reallocated.	NIR chapter 2 and 9
1.A Fuel combustion – sectoral approach – other fossil fuels, biomass – CO2, CH4, N2O	The ERT recommends that the Party (a) split the AD and CH4 and N2O 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 CO2 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	
1.A. Fuel combustion – sectoral approach – liquid fuels – CO2	The ERT recommends that Norway 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
1.A Fuel combustion – sectoral approach all fuels – CO2	The ERT rcommends that Norway provide in its NIR an improved discussion of the reliability of the national CO2 emission estimates for fuel combustion (estimated using the sectoral approach) that better	ARR/2022 E.9 (ARR/2020 E.26)	Addressing. We are working on an improved discussion on CO2 emissions.	Section 3.6.1 and Annex XII

	supports the Party's claim of the accuracy and completeness of reported emissions from fuel combustion (category 1.A).			
1.A.1.a	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.	
1.A.2.a Iron and steel – solid fuels – CO2	The ERT recommends that Norway 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
1.A.2.a Iron and steel – solid fuels – CO2	The ERT recommends that the Party investigate the underlying reason where large inter-annual fluctuations in the CO2 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
1.A.2.c Chemicals – liquid fuels – CO2, CH4, N2O	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 CO2 emissions.	ARR/2022 E.25	Addressed. Included in the 2023 submission	CRF 1A2C liquid
1.A.2.f Non-metallic minerals – solid fuels – CO2, CH4, N2O	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. Reallocated to other fossile fuels.	CRF, Section 10.2.2 and Section 3.2.3.7
1.A.3.b Road transportation – gasoline, diesel oil– CO2	The ERT recommends that the Party determine when and how the country-specific CO2 EFs for gasoline and diesel oil from the Norwegian pollution control agency 1999 report were derived and either justify that these CO2 EFs are still valid for the most recent years or revise the EFs across the time series	ARR/2022 E.27	Addressing. We have compared the CO2 EFs to other sources, incl. IPCC default factors and factors used by other countries. Based on this, we see that our CO2 EFs seem reasonable. We will continue to check and verify the factor as new data become available eg., when	

			road traffic is included in the EU ETS.	
1.A.4.a Commercial/institutional – gaseous fuels – CO2, CH4, N2O	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
1.A.4.b Residential – biomass – CO2, CH4, N2O	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
1.A.4.b Residential – biomass – CH4	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 CH4 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
1.B Fugitive emissions from fuels - all fuels – CO2, CH4, NMVOC	"The ERT recommends that the Party make efforts to report indirect CO2 emissions in CRF table 6, excluding them from sectoral CRF tables 1.B.1 and 1.B.2. In addition, the ERT encourages Norway to clarify in the NIR	ARR/2022 E.13 (ARR/2020 E.28)	Addressed. Implement in the 2023 submission.	Section 3.3.1 and 3.4.1.4
1.B.2 Oil and natural gas and other – gaseous fuels – CO2 and CH4	that the NMVOC emission estimates used to estimate indirect CO2 emissions for the national GHG inventory are the same as those reported under the Convention on Long-range Transboundary Air Pollution. "	ARR/2022 E.15 (ARR/2020 E.17, ARR/2018E.28, ARR/2016E.33)	Addressed. 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 implemented.	Section 3.4
1.B.2 Oil, natural gas and other emissions from energy production liquid and gaseous fuels– CH4 and CO2	The ERT recommends that Norwqay report emissions at the level of data entry in CRF table 1.B.2, providing AD and CO2 and CH4 emission estimates (or notation keys) for all subcategories, as appropriate.	ARR/2022 E.16 (ARR/2020 E.18, ARR/2018 E.36)	Addressed. 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	Section 3.4

			input in the CRF is implemented.	
1.B.2 Oil, natural gas and other emissions from energy production gaseous and liquid fuels– CH4 and CO2	The ERT recommends that Norway 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. The ERT also recommends that Norway report disaggregated emissions per subcategory and avoid using "IE", or, where this is not possible, provide transparent justification in the NIR for use of this notation key.	ARR/2022 E.17 (ARR/2020 E.20, ARR/2018 E.37)	Addressed. A new method for venting was implemented in the inventory in the NIR 2020. The documentation in the NIR has since been improved.	Section 3.4
1.B.2 Oil, natural gas and other emissions from energy production gaseous and liquid fuels– CH4 and CO2	The ERT recommends that Norway 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.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.	Section 3.4
1.B.2 Oil, natural gas and other emissions from energy production – CO2	The ERT also recommends that Norway 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 CH4 in particular, in order to provide assurance of the completeness and accuracy of the national inventory.	ARR/2022 E.31	Not addressed	
1.B.2 Oil, natural gas and other emissions from energy production – CO21.B.2 Oil, natural gas	The ERT recommends that the Party estimate the missing direct CO2 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.32	Not addressed	

and other emissions from energy production – CH4				
1.B.2.a Oil – liquid fuels – CO2	The ERT recommends that the Party recalculate the venting and fugitive CH4 emissions for subcategory 1.B.2.c.1.iii venting (combined) for 1990–2016 and explain the recalculations in the NIR	ARR/2022 E.20 (ARR/2020 E.24)	Addressed. A more systematic routine for reporting on recalculations has been established.	Chapters 10 and 3
Fuel combustion – reference approach – solid fuels CO2	The ERT recommends that the Party 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.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
Fuel combustion – reference approach – solid fuels – CO2	The ERT recomends to improve the data collection procedures for solid fuels (coal and coke oven coke)	ARR/2022 E.4 (ARR/2020 E.4, ARR/2018 E.5, ARR/2016 E.17)	Addressed: Improved data collection and QA/QC-routins are incorperated. Documentation in Annex XII is updated and improved.	Section 3.6.1 and Annex XII
General (IPPU)	The ERT recommends that Norway, in order to improve the comparability and transparency of its reporting, exclude indirect CO2 emissions from the sectoral (direct) CO2 emissions in the IPPU sectoral tables and report indirect CO2 emissions from the IPPU sector in CRF table 6.	ARR/2022 I.2 (ARR/2020 I.11)	Addressed. Implemented in the CRF and documented in the NIR.	CRF and chapter 9.
2.B.8 Petrochemical and carbon black production – CH4	The ERT recommends that the Party recalculate CH4 emissions from methanol production (category 2.B.8.a) from 2013 onward and explain the recalculation in the NIR, and until that is done, explain in the NIR that the methods for measuring and reporting CH4 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.	ARR/2022 I.21	Addressed. The time series for CH4 from 2B8a has been recalculated.	4.3.6.2
2.C.6 Zinc production – CO2	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 are reported in the CRF.	NIR section 4.4.5.3 and CRF Table 2(I).A-Hs2

2.D Non-energy products from fuels and solvent use - CH4, N2O	The ERT recommends that the Party apply correct notation keys for recovery of CH4 and N2O for lubricant use and solvent use (categories 2.D.1 and 2.D.3.a) in CRF table 2(I).A-Hs2.	ARR/2022 I.6 (ARR/2020 I.15)	Addressed. Notation keys have been changed.	
2.D.3 Other (non-energy products from fuels and solvent use) – CO2	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 CO2 emissions from solvent use, reported under category 2.D.3, in 2018-2020 (CO2 emissions were 112.03, 87.73 and 122.15 kt CO2 eq for 2018, 2019 and 2020 respectively).	ARR/2022 I.23	Addressed. A description of sensitivity in inter-annual changes in the activity data is included in NIR.	NIR chapter 4.5.3.2
2.E Electronics industry – HFCs	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	Addressed. The text on this matter in the documentation box has been removed.	CRF Table 2(II)B-Hs2
2.E.1 Integrated circuit or semiconductor - SF6	The ERT recommends that 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)	Addressed. The time series for 2E1 has been revised and is due to confidentiality reported as included elsewhere (in 2G1).	4.6.1
2.F.1 Refrigeration and air conditioning – HFCs	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.	CRF table 2(II)B-Hs2 and section 4.7.1.1
2.F.1 Refrigeration and air conditioning - HFC	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.
2.F.1 Refrigeration and air conditioning – HFCs and PFCs	"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	ARR/2022 I.12 (ARR/2020 I.7, ARR/2018 I.27)	Addressed. New emission factors are implemented, with	4.7.1 and 10.1.1.2

	associations on EFs and use practices, use of blends), especially for more significant applications, and report on progress in the NIR.		explanations, for all significant applications. In the 2024-submission the recovery rates are evaluated and implemented. Documentation is included in the 2024 NIR.	
3.A Enteric fermentation – CH4	The ERT recommends that the Party report the weight and typical animal mass for as many livestock types as possible (e.g. sheep, swine, deer, goats, horses, poultry, reindeer and fur-bearing animals) in CRF tables 3.As2 and 3.B(b), even when such parameters are not used in the estimation of emissions, or, alternatively, report the parameters as "NA" in CRF tables 3.As2 and 3.B(b) if it does not use them in the estimation of emissions fromenteric fermentation and manure management and explain in the NIR the reason for using "NA".	ARR/2022 A.1	Addressed. Notation keys are changed to NA in the CRF.	
3.B Manure management – N2O	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.	ARR/2022 A.4	Addressed. This is correctly reported in the 2023 CRF.	
3.B Manure management – CH4	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).	ARR/2022 A.5	Addressed. Implemented in the UNFCCC submission 2023.	NIR section 5.3.1.1.1.1
3.B Manure management – CH4	The ERT recommends that the Party explain in the NIR that the source of the values for the MCF for pasture range and paddock is the 2019 Refinement to the 2006 IPCC Guidelines (vol. 4, chap.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.	ARR/2022 A.6	Addressed. Implemented in the UNFCCC submission 2023.	NIR section 5.3.1.1.1.1

3.B Manure management – N2O	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 CRF.	
3.F Field burning of agricultural residues – CH4, N2O	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, for example 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 section 5.5.1
3.F.1 Cereals - CH4 and N2O	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”.	ARR/2022 A.8	Addressed. Notation keys are changed in the CRF.	
4.A.1 Forest land remaining forest land - CO2 and N2O	The ERT recommends that Norway 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 currently 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. The first one (long term) consists of a national soil carbon monitoring program within the NFI, which sampled 104 plots in 2023. These samples will help produce independent data which can be used to	Ch. 6.4.1.3

			verify (evaluate) the Yasso07 on a national scale. The second one (short term) uses soil C stock measurements taken 10 years apart (i.e. base-line in 2012 and one re-sample in 2022) on each of 6 sites with a more precise and accurate field protocol than used on the NFI sites. Most of these 6 sites are found in the south-east of Norway, where also most of the forest is located. A comparison between Yasso07 and sample-based estimates of soil C and soil C changes on these 6 sites will be used in the verification process. More details on these projects were provided in chapter 6.4.1.3 of NIR.	
4.A.1 Forest land remaining forest land - CO2 and N2O	The ERT recommends that Norway, pending the start of additional data collection, apply alternative means of verification, such as chrono-sequences 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. In addition to the programs mentioned in the MS response to the ARR 2022 L.11 (ARR/2020 L.15, ARR/2018 L.17), Norway has applied some alternative means of verification/evaluation of the model output, as suggested. The	Ch. 6.4.1.3

			conclusions from a validation project are described in Dalsgaard, et al. (2017). More details on these initiatives were provided in chapter 6.4.1.3 of NIR2023. Reference: Dalsgaard, L., Kjønaas, O. J. & Lange, H. (2017): Forest soil carbon changes from measurements and models. Site-specific comparisons and implications for UNFCCC reporting. Ås: Norwegian Institute for Bioeconomy Research. 112 pp	
4.A.1 Forest land remaining forest land - CO2 and N2O	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 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.	ARR/2022 L.23	Addressing. Given that a Tier2 method will need data to represent the effect of forest management and that such empirical data does not exist for Norway (thus use of model is necessary), Norway argues that model validation (evaluation) is necessary for both Tier2 and Tier3 methods. Thus, Norway focus on model validation with parts of south east Norway in the short	Ch. 6.4.1.3

			term and nationally in the long term.	
5.A.1 Managed waste disposal sites – CH4 Completeness	The ERT recommends that Norway 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, 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.
5.B Biological treatment of solid waste – CH4 and N2O Accuracy	The ERT recommends that Norway apply, in line with the 2006 IPCC Guidelines, the tier 2 method, using country-specific EFs, to estimate CH4 and N2O emissions from the biological treatment of solid waste for the next submission.	ARR/2022 W.4 (ARR/2020W.3, ARR/2018 W.15)	Addressing.	7.4.1.8.
5.D Wastewater treatment and discharge – CH4 Transparency	The ERT recommends that Norway present total organic product data in the NIR and in CRF table 5.D	ARR/2022 W.5 (ARR/2020 W.4, ARR/2015 W.8, ARR/2016 W.8, ARR/2018 W.7,)	Addressed. Total organic product for domestic wastewater is included	7.6.3
5.D.2 Industrial wastewater – N2O Completeness	The ERT recommends that Norway report N2O emissions from the industrial wastewater treated in domestic WWTP.	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.	7.6.4

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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.

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