M-2613|2023

# Calculation of atmospheric nitrogen emissions from crop residues in Norwegian agriculture

Technical description of the revised model

Project for Norwegian Environment Agency and SSB

Calculation of atmospheric nitrogen emissions from crop residues in Norwegian agriculture

CARBON LIMITS

## Abstract

Crop residues affect the nitrogen (N) content of the soils, which, in turn, influences the amount of nitrous oxide ($N_2O$) and ammonia ($NH_3$) released to the air. The N content returned to soil notably depends on the amount and type of crop, as well as the crop residue management. These parameters need to be taken into consideration when building a model to calculate N content from crop residues.

A revised excel model for calculating N content from crop residues for the Norwegian agriculture has been developed by Carbon Limits. The model is built on the previously used model, developed by Bioforsk and operated by Statistics Norway (SSB). The model allows to calculate N content from different types of crop residues as well as the associated $N_2O$ and $NH_3$ emissions per year. The calculations follow Tier 1 methodology and are based on the equations updated by the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

This report describes the methodology implemented in the updated model, the most important changes from the previous version of the model, as well as the main input data and factors used.

CARBON LIMITS

CJ Hambros plass 2

NO-0164 Oslo

Norge

carbonlimits.no

NO 988 457 930

# Table of Contents

# 1. Introduction

The main objective of the project was to update the existing model for nitrogen (N) content in crop residues developed by Bioforsk in 2014 and operated by Statistics Norway (SSB). The updated model calculates N content in crop residues and the associated emissions of nitrous oxide ($N_2O$), based on the methodology described by the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereafter IPCC 2019)[1], and the associated emissions of ammonia ($NH_3$), based on the methodology described by the *EMEP/EEA air pollutant emission inventory guidebook 2023*[2]. The former model was based on the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[3].

The new version of the model features several changes in the formulae used to calculate the N content in crop residues, as well as changes in the determination of some parameters. Table 1 below summarizes these changes.

Table 1 – Summary of the modifications in the update of the model.

| Modification | Affected crop types | Impact on results |
|---|---|---|
| Calculations of $N_2O$ and $NH_3$ emissions from the N content. | All | Additional results incorporated in the model |
| Update of the Equation 11.6 from IPCC 2006 to IPCC 2019. | All | Decrease of N content estimate for crops with straw-like residues[4]. Results unchanged for the others. |
| Change of the method to determine the quantity of above-ground residues. | All | Increase of the estimate for the N content. |
| Inclusion of the combustion factor in the formulae. | Crops with straw-like residues. | Increase of the estimate for the N content. |

[1] Hergoualc'h et al., "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories". *Volume 4: Agriculture, Forestry and Other Land Use*. *Chapter 11: $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application*. 2019. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

[2] Hutchings et al., "EMEP/EEA air pollutant emission inventory guidebook 2023". *Chapter 3.D Agricultural soils*. 2023. Retrieved from: https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/3-agriculture/3-d-agricultural-soils-2023/view .

[3] De Klein et al., "2006 IPCC Guidelines for National Greenhouse Gas Inventories". *Volume 4: Agriculture, Forestry and Other Land Use. Chapter 11: $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application*. 2006. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

[4] In this report, "crop with straw-like residues" refers to crop types for which the residues can be used as straw for bedding, forage, construction and/or that are burnt.

# 2. Calculation of N content and gas emissions

## 2.1 Methodology

The N content in crop residues is determined using the Tier 1 methodology from the IPCC guidelines. More specifically, the calculations are based on the updated Equation 11.6 from IPCC 2019:

$$F_{CR} = \sum_{T} \{[AGR_{(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)} - (Frac_{Burnt(T)} \times C_f))] + [BGR_{(T)} \times N_{BG(T)}]\}$$

Where:

| | |
|---|---|
| $F_{CR}$ | = annual amount of N in crop residues (above and below ground), kg N $yr^{-1}$ |
| $T$ | = crop or forage type |
| $AGR_{(T)}$ | = annual total amount of above-ground crop residue for crop $T$, kg d.m. $yr^{-1}$ |
| $N_{AG(T)}$ | = N content of above-ground residues for crop $T$, kg N $(kg\ d.m.)^{-1}$ |
| $Frac_{Remove(T)}$ | = fraction of above-ground residues of crop $T$ removed annually for purposes such as feed, bedding and construction, dimensionless |
| $Frac_{Burnt(T)}$ | = fraction of annual harvested area of crop $T$ burnt, dimensionless |
| $C_f$ | = combustion factor (dimensionless) |
| $BGR_{(T)}$ | = annual total amount of belowground crop residue for crop $T$, kg d.m. $yr^{-1}$ |
| $N_{BG(T)}$ | = N content of below-ground residues for crop $T$, kg N $(kg\ d.m.)^{-1}$ |

*NB*: d.m. stands for "dry matter"

According to Equations 11.1 and 11.6 of IPCC 2019, direct emissions of $N_2O$ are calculated by multiplying the N content of crop residues by an emission factor:

$$N_2O - N = F_{CR} \times EF_{N_2O}$$

$$N_2O = N_2O - N \times 44/28$$

Where:

| | |
|---|---|
| $N_2O - N$ | = annual direct $N_2O$–N emissions from N inputs in crop residues to managed soils, kg $N_2O$–N $yr^{-1}$ |
| $EF_{N_2O}$ | = emission factor for $N_2O$ emissions from N inputs, kg $N_2O$–N (kg N input)$^{-1}$ |
| $N_2O$ | = annual direct $N_2O$ emissions from N inputs in crop residues to managed soils, kg $N_2O$ $yr^{-1}$ |

Similarly, emissions of $NH_3$ are calculated following the tier 1 approach as described by the *EMEP/EEA air pollutant emission inventory guidebook 2023*[5]*:*

$$NH_3 = F_{CR} \times EF_{NH_3}$$

Where:

| | |
|---|---|
| $EF_{NH_3}$ | = emission factor for $NH_3$ emissions from N inputs, kg $NH_3$(kg N input)$^{-1}$ |
| $NH_3$ | = annual direct $NH_3$ emissions from N inputs in crop residues to managed soils, kg $NH_3$ yr$^{-1}$ |

## 2.2 Inputs to the model

The model uses as inputs the annual harvested fresh quantity for each crop, expressed in kg fresh weight. For a crop $T$, this quantity is noted $Yield\ Fresh_{(T)}$. Note that, contrary to Equations 11.6 and 11.7 of IPCC 2019, the yield is expressed in kg and not kg.ha$^{-1}$. Hence, the parameter $Area_{(T)}$ is not used in this model.

The types of crops are:

- Hay
- Wheat
- Rye
- Triticale
- Barley
- Oat
- Oil seeds
- Potatoes
- Tubers
- Green forages
- Vegetables
- Peas
- Beans

In the model, the crop "Hay" is divided into two crop types: "Perennial grass" and "Grass-clover mixtures".

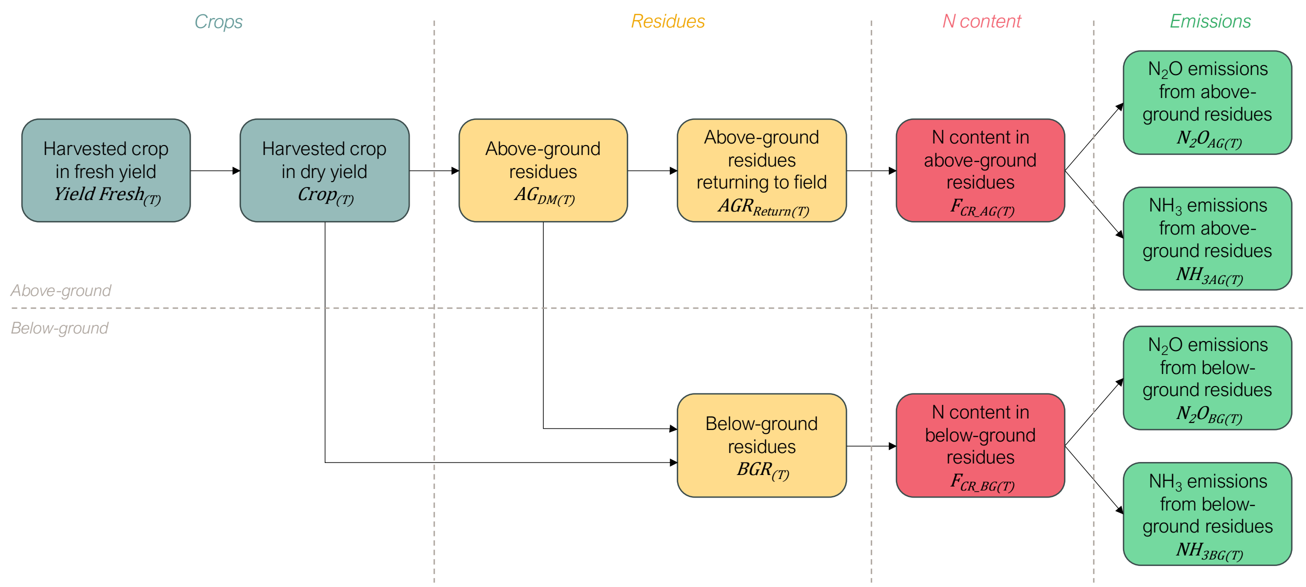
## 2.3 Calculation steps and parameters

In the updated model, the calculations based on Equation 11.6 of IPCC 2019 are broken down into several steps to obtain results per crop type, as well as to calculate the emissions separately for above-ground and below-ground residues (where Equation 11.6 from IPCC 2019 only gives the sum through $F_{CR}$). Therefore, the model introduces

[5] Hutchings et al., "EMEP/EEA air pollutant emission inventory guidebook 2023". *Chapter 3.D Agricultural soils*. 2023. Retrieved from: https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/3-agriculture/3-d-agricultural-soils-2023/view .

notations for parameters that are not directly taken from the IPCC. Table 2, at the end of this section, shows a summary of the parameters used in the model, indicates the sources used and specifies if the parameter was introduced for the purposes described above or directly taken from the referenced equation. Figure 1 summarizes the main calculation steps used in the model.

Figure 1 – Main calculation steps in the model




## 2.3.1 Quantity of harvested crops in dry matter mass

The first step is to calculate the annual quantity of crops harvested in kg dry matter. For each crop $T$, this quantity is noted $Crop_{(T)}$ and is obtained by multiplying the quantity in fresh weight $Yield\ Fresh_{(T)}$ by the dry matter fraction of the crop $T\,(DRY_{(T)})$.

$Yield\ Fresh_{(T)}$ is the main user input in the model (“INPUT-SSB” tab). The dry matter fraction $DRY_{(T)}$ can be changed in the “INPUT – FACTORS” tab. The values for this parameter detailed per crop type are available in Table 4 in Appendix A.

For the crop type “Grass-clover mixtures”, the quantity of harvested crop is obtained by multiplying the quantity of harvested hay by the fraction grass-clover mixtures in the hay. This parameter noted $\%clover$ is entered, per year, in the “INPUT – FACTORS” tab. A fixed value of 55% taken from Grønlund et al. (2014)[6] (hereafter “Bioforsk report”) was used. The quantity of “Perennial grass” corresponds to the rest of the hay quantity.

The calculations carried out at this first step are based on the following equation:

[6] Grønlund et al., «Nitrogen I restavlinger Oppdatering av koeffisienter for beregning av lystgass fra restavlinger», Bioforsk rapport, 2014

$$Crop_{(T)} = \begin{cases} Yield\ Fresh_{(Hay)} \times (1 - \%clover) \times DRY_{(T)} & \text{if } T = \text{"}Perennial\,grass\text{"} \\ Yield\ Fresh_{(Hay)} \times \%clover \times DRY_{(T)} & \text{if } T = \text{"}Grass - clover\ mixtures\text{"} \\ Yield\ Fresh_{(T)} \times DRY_{(T)} & \text{else} \end{cases}$$

### 2.3.2 Fraction of different practices in crop and crop residues management

The second step is to calculate the quantity of above-ground residues that returns to soil, using the parameters referring to crop and crop residues management.

The model calculates the fraction of total area under crop $T$ that is renewed annually ($Frac_{Renew(T)}$), which is equal to the inverse of the renewing period. The renewing period, noted $P_{Renew(T)}$[7], is entered per year in the “INPUT – FACTORS” tab. A fixed value of 10 years is used for perennial grass and grass-clove mixtures (taken from the Bioforsk report[8]), and 1 year is used for other crops.

$$Frac_{Renew(T)} = 1/P_{Renew(T)}$$

The fraction of above-ground residues of crop $T$ removed annually for purposes such as feed, bedding, and construction ($Frac_{Remove(T)}$) and the fraction of annual harvested area burnt ($Frac_{Burnt(T)}$) are directly entered in the model in the “INPUT – FACTORS” tab. The values of these parameters are entered for each year.

The values used for $Frac_{Remove(T)}$ are available in Table 6 in Appendix A, while the values used for $Frac_{Burnt(T)}$ are provided in Table 7 in Appendix A.

### 2.3.3 N content in above-ground residues

First, the quantity of above-ground residues due to crop $T$, $AG_{DM(T)}$, is calculated by multiplying the quantity of crop by the ratio of above-ground residue dry matter to harvested yield. This parameter noted $R_{AG(T)}$ is expressed in kg d.m. (kg d.m.) $^{-1}$ and is entered in the “INPUT – FACTORS” tab. The detail per crop type is given in

[7] This parameter corresponds to the factor $X$ in the description of Equation 11.6 in IPCC 2019
[8] Grønlund et al., «Nitrogen I restavlinger Oppdatering av koeffisienter for beregning av lystgass fra restavlinger», Bioforsk rapport, 2014

Table 5 in Appendix A.

The calculation, extracted from Equation 11.6 of IPCC 2019 is represented as follows:

$$AG_{DM(T)} = Crop_{(T)} \times R_{AG(T)}$$

This allows to calculate the annual quantity of above-ground residues for crop $T$:

$$AGR_{(T)} = Frac_{Renew(T)} \times AG_{DM(T)}$$

This equation is not explicitly described in IPCC 2019. It was deduced by analyzing the physical meaning of the different parameters and was confirmed by the comparison of the former and new equations 11.6 (see Appendix B).

Then, the annual quantity of above-ground residues that is returned to the soil due to crop $T$, noted $AGR_{Return(T)}$, is calculated according to the following equation:

$$AGR_{Return(T)} = AGR_{(T)} \times (1 - Frac_{Remove(T)} - (Frac_{Burnt(T)} \times C_{f(T)}))$$

This corresponds to the above-ground part of Equation 11.6 in IPCC 2019. The combustion efficiencies $C_{f(T)}$ are entered in the "INPUT – FACTORS" tab. Values used are provided in Table 8 in Appendix A.

Finally, the quantity of nitrogen in above-ground residues, $F_{CR-AG(T)}$, is calculated using the N content of above-ground residues. This parameter, noted $N_{AG(T)}$, is expressed in kg N (kg d.m.) $^{-1}$ and is entered in the "INPUT – FACTORS" tab. The values used are displayed in Table 10 in Appendix A. The calculations are based on Equation11.6 of IPCC 2019 and are summarized by the following equation:

$$F_{CR-AG(T)} = AGR_{Return(T)} \times N_{AG(T)}$$

### 2.3.4 $N_2O$ and $NH_3$ emissions from above-ground residues

Emissions of $N_2O$ are calculated by multiplying the N content by an emission factor $EF_{N_2O(T)}$. This parameter is entered in the "INPUT – FACTORS" tab. Emissions from the above-ground residues are calculated as follows:

$$N_2O_{AG(T)} = F_{CR-AG(T)} \times EF_{N_2O(T)} \times 44/28$$

Following the IPCC default factor (taken from Table 11.1 of IPCC 2019), for all crops, the emission factor is: $EF_{N_2O(T)} = 0.006 \text{ kg } N_2\text{O– N } (kg\ N)^{-1}$ presuming 100% wet climate in agricultural land in Norway. The factor $44/28$ converts $\text{kg } N_2\text{O– N}$ into $\text{kg } N_2\text{O}$.

Similarly, emissions of $NH_3$ are calculated by multiplying the N content by an emission factor $EF_{NH_3(T)}$. This parameter is entered in the "INPUT – FACTORS" tab. Emissions from the above-ground residues are calculated as follows:

$$NH_{3\,AG(T)} = F_{CR-AG(T)} \times EF_{NH_3(T)}$$

Based on the *EMEP/EEA air pollutant emission inventory guidebook 2023*[9], for all crops, the following emission factor is used in the model: $EF_{NH_3(T)} = 0.068 \text{ kg } NH_3\ (kg\ N)^{-1}$.

### 2.3.5 N content in below-ground crop residues

The quantity of below-ground crop residues, $BGR_{(T)}$, is calculated from the quantity of above-ground biomass using the ratio of below-ground root biomass to above-ground shoot biomass $RS_{(T)}$. This parameter is expressed in kg d.m. (kg d.m.) $^{-1}$ and is entered in the "INPUT – FACTORS" tab. The values used for this parameter are summarized in Table 9 in Appendix A.

The following equation, taken from Equation 11.6 in IPCC 2019, is used:

$$BGR_{(T)} = (Crop_{(T)} + AG_{DM(T)}) \times RS_{(T)} \times Frac_{Renew(T)}$$

Then quantity of nitrogen in below-ground residues, $F_{CR-BG(T)}$, is calculated using the N content of below-ground residues for crop $T$. This parameter, noted $N_{BG(T)}$, is expressed in kg N (kg d.m.) $^{-1}$ and is entered in the "INPUT – FACTORS" tab. The values used are displayed in Table 11 in Appendix A. The calculations are based on Equation11.6 of IPCC 2019 and are summarized by the following equation:

$$F_{CR-BG(T)} = BGR_{(T)} \times N_{BG(T)}$$

### 2.3.6 $N_2O$ and $NH_3$ emissions from below-ground residues

Emissions of $N_2O$ and $NH_3$ are calculated the same way as for above-ground residues by multiplying the N content by an emission factor. The emissions factors $EF_{N_2O(T)}$ and $EF_{NH_3(T)}$ are the same as for above-ground residues. Emissions from above-ground residues are thus calculated as follows:

$$N_2O_{BG(T)} = F_{CR-BG(T)} \times EF_{N_2O(T)} \times 44/28$$

$$NH_{3\,BG(T)} = F_{CR-BG(T)} \times EF_{NH_3(T)}$$

### 2.3.7 Total N content and emissions per crop type

For each crop type, the total annual N content is the sum of the N content of above-ground residues and of below-ground residues:

$$F_{CR(T)} = F_{CR-AG(T)} + F_{CR-BG(T)}$$

Following the same logic, the model calculates the total $N_2O$ and $NH_3$ emissions due to crop residues for crop $T$:

$$N_2O_{(T)} = N_2O_{AG(T)} + N_2O_{BG(T)}$$

$$NH_{3(T)} = NH_{3\,AG(T)} + NH_{3\,BG(T)}$$

[9] Hutchings et al., "EMEP/EEA air pollutant emission inventory guidebook 2023". *Chapter 3.D Agricultural soils*. 2023. Retrieved from: https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/3-agriculture/3-d-agricultural-soils-2023/view .

### 2.3.8 Total N content and emissions

Finally, the total annual N content is calculated as the sum of the N content of residues for all crop types:

$$F_{CR} = \sum_{T} F_{CR(T)}$$

The total annual $N_2O$ emissions due to all crop residues are:

$$N_2O = \sum_{T} N_2O_{(T)}$$

And the total annual $NH_3$ emissions due to all crop residues are:

$$NH_3 = \sum_{T} NH_{3(T)}$$

Table 2 below summarizes the parameter used in the model.

Table 2 – Summary of the parameters in the model

| Parameter | Description | Unit | Value from | Reference |
|---|---|---|---|---|
| $\boldsymbol{\%clover}$ | Fraction of grass-clover mixtures in the hay | - | Bioforsk report | Introduced by the model |
| $\boldsymbol{AG_{DM(T)}}$ | Above-ground residue dry matter for crop $T$ | kg d.m. | Calculated in the model | IPCC 2019, Equation 11.6 |
| $\boldsymbol{AGR_{(T)}}$ | Annual total amount of above-ground crop residue for crop $T$ | kg d.m. | Calculated in the model | IPCC 2019, Equation 11.6 |
| $\boldsymbol{AGR_{Return(T)}}$ | Annual total amount of above-ground crop residue returned to the soil for crop $T$ | kg d.m. | Calculated in the model | Introduced by the model |
| $\boldsymbol{BGR_{(T)}}$ | Annual total amount of belowground crop residue for crop $T$ | kg d.m. | Calculated in the model | IPCC 2019, Equation 11.6 |
| $\boldsymbol{C_{f(T)}}$ | Combustion factor crop $T$ | - | IPCC 2019 | IPCC 2019, Equation 11.6 |
| $\boldsymbol{Crop_{(T)}}$ | Harvested dry matter quantity for crop $T$ | kg d.m. | Calculated in the model | IPCC 2019, Equation 11.7 |

| Parameter | Description | Unit | Value from | Reference |
|---|---|---|---|---|
| $DRY_{(T)}$ | Dry matter fraction of harvested crop $T$ | kg d.m. (kg fresh weight)$^{-1}$ | IPCC 2019 and Bioforsk report | IPCC 2019, Equation 11.7 |
| $EF_{N_2O(T)}$ | Emission factor for $N_2O$ emissions from N in crop residues for crop $T$ | kg $N_2O$–N (kg N)$^{-1}$ | IPCC 2019 | Introduced by the model |
| $EF_{NH_3(T)}$ | Emission factor for $NH_3$ emissions from N in crop residues for crop $T$ | kg $NH_3$ (kg N)$^{-1}$ | Hutchings et N et al. (2023) | Introduced by the model |
| $F_{CR(T)}$ | Annual amount of N in crop residues for crop $T$ | kg N | Calculated in the model | Introduced by the model |
| $F_{CR}$ | Total annual amount of N in crop residues | kg N | Calculated in the model | IPCC 2019, Equation 11.6 |
| $F_{CR-AG(T)}$ | Annual amount of N in above-ground crop residues returned to the soil for crop $T$ | kg N | Calculated in the model | Introduced by the model |
| $F_{CR-BG(T)}$ | Annual amount of N in below-ground crop residues for crop $T$ | kg N | Calculated in the model | Introduced by the model |
| $Frac_{Burnt(T)}$ | Fraction of annual harvested area of crop $T$ burnt | - | Note from SLF (2011) | IPCC 2019, Equation 11.6 |
| $Frac_{Remove(T)}$ | Fraction of above-ground residues of crop $T$ removed annually for purposes such as feed, bedding and construction. | - | Expert judgement (2005) | IPCC 2019, Equation 11.6 |
| $Frac_{Renew(T)}$ | Fraction of total area under crop $T$ that is renewed annually | - | Calculated in the model | IPCC 2019, Equation 11.6 |
| $N_2O$ | Emissions of $N_2O$ from crop residues | kg $N_2O$ | Calculated in the model | Introduced by the model |
| $N_2O_{(T)}$ | Emissions of $N_2O$ from crop residues for crop $T$ | kg $N_2O$ | Calculated in the model | Introduced by the model |
| $N_2O_{AG(T)}$ | Emissions of $N_2O$ from above-ground crop residues for crop $T$ | kg $N_2O$ | Calculated in the model | Introduced by the model |
| $N_2O_{BG(T)}$ | Emissions of $N_2O$ from below-ground crop residues for crop $T$ | kg $N_2O$ | Calculated in the model | Introduced by the model |

| Parameter | Description | Unit | Value from | Reference |
|---|---|---|---|---|
| $\boldsymbol{N_{AG(T)}}$ | N content of above-ground residues for crop $T$ | kg N (kg d.m.) $^{-1}$ | IPCC 2019 and Bioforsk report | IPCC 2019, Equation 11.6 |
| $\boldsymbol{N_{BG(T)}}$ | N content of below-ground residues for crop $T$ | kg N (kg d.m.) $^{-1}$ | IPCC 2019 and Bioforsk report | IPCC 2019, Equation 11.6 |
| $\boldsymbol{NH_3}$ | Emissions of $NH_3$ from crop residues | kg $NH_3$ | Calculated in the model | Introduced by the model |
| $\boldsymbol{NH_{3(T)}}$ | Emissions of $NH_3$ from crop residues for crop $T$ | kg $NH_3$ | Calculated in the model | Introduced by the model |
| $\boldsymbol{NH_{3AG(T)}}$ | Emissions of $NH_3$ from above-ground crop residues for crop $T$ | kg $NH_3$ | Calculated in the model | Introduced by the model |
| $\boldsymbol{NH_{3BG(T)}}$ | Emissions of $NH_3$ from below-ground crop residues for crop $T$ | kg $NH_3$ | Calculated in the model | Introduced by the model |
| $\boldsymbol{P_{Renew(T)}}$ | Renewing period for crop $T$ | year | Bioforsk report | Introduced by the model (corresponds to parameter $X$ in the text of Equation 11.6 in IPCC 2019) |
| $\boldsymbol{R_{AG(T)}}$ | Ratio of above-ground residue dry matter to harvested yield for crop $T$ | kg d.m. (kg d.m.)$^{-1}$ | IPCC 2019 and Bioforsk report | IPCC 2019, Equation 11.6 |
| $\boldsymbol{RS_{(T)}}$ | Ratio of below-ground root biomass to above-ground shoot biomass for crop $T$ | kg d.m. (kg d.m.)$^{-1}$ | IPCC 2019 | IPCC 2019, Equation 11.6 |
| $\boldsymbol{Yield\ Fresh_{(T)}}$ | Annual harvested fresh quantity for crop $T$ | kg fresh weight | Input from Statistics Norway | IPCC 2019, Equation 11.7 |

## 3. Changes compared to the previous version of the model.

The updated model to calculate N content in crop residues features several updates compared to the version previously used by SSB. Therefore, for the same input data, results may differ between the two versions. For instance, depending on the crop type, the calculated N content for year 2021 is up to 131% larger in the updated version than it was in the former version (see Table 3). The possible explanations behind these differences are detailed in the following sections.

Table 3 – Total N content of crop residues, per crop, for year 2021 calculated by the previous and the updated versions of the model. Results are expressed in kg N.

| Crop type | Total N content – Former version | Total N content – Updated version | Difference |
|---|---|---|---|
| Perennial grass | 2,237,352 | 2,237,352 | 0% |
| Grass-clover mixtures | 3,297,232 | 3,297,232 | 0% |
| Wheat | 1,529,776 | 1,563,725 | +2.2% |
| Rye | 303,857 | 312,664 | +2.9% |
| Triticale | 0.00 | 0.00 | 0% |
| Barley | 4,201,431 | 5,913,688 | +41% |
| Oat | 1,332,767 | 1,753,535 | +32% |
| Oil seeds | 118,694 | 139,215 | +17% |
| Potatoes | 404,167 | 934,940 | +131% |
| Tubers | 0.00 | 0.00 | 0% |
| Green forages | 2,116,951 | 2,116,951 | 0% |
| Vegetables | 222,061 | 513,682 | +131% |
| Peas | 57,711 | 101,117 | +75% |
| Beans | 4,234 | 7,419 | +75% |

## 3.1 Change of method in IPCC

### 3.1.1 Expression of the total N content

In the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories,* Equation 11.6 was updated. The previous version of the model uses Equation 11.6 provided in IPCC 2006:

$$F_{CR} = \sum_{T}\{Crop_{(T)} \times Frac_{Renew(T)} \times \left[(Area_{(T)} - Area_{Burnt(T)} \times C_f) \times R_{AG(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)}) + (Area_{(T)} \times R_{BG(T)} \times N_{BG(T)}\right]\}$$

The updated version of the model uses Equation 11.6 provided in IPCC 2019:

$$F_{CR} = \sum_{T}\{\left[AGR_{(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)} - (Frac_{Burnt(T)} \times C_f))\right] + \left[BGR_{(T)} \times N_{BG(T)}\right]\}$$

A detailed comparison of the two equations is available in Appendix B. Equation 11.6 in IPCC 2019 is mostly a re-writing of Equation 11.6 in IPCC 2006 with some changes in notations. However, there has been a small change in the expression: a factor $Frac_{remove} \times Frac_{burnt} \times C_f$ has been removed from the formula for the N content of above-ground residues (see Appendix B for more details). This causes the estimation of N content in above-ground residues to be slightly lower (by 1 to 7%), for some crops, when using the updated version of Equation 11.6 compared to the previous one.

### 3.1.2 Determination of the ratio of above-ground residue dry matter

In the previous version of the model, the ratio of above-ground residue dry matter $AG_{DM(T)}$ is calculated using the following formula, extracted from Table 11.2 of IPCC 2006:

$$AG_{DM(T)} = Crop_{(T)}/1000 \times slope_{(T)} + intercept_{(T)}$$

Where $slope_{(T)}$and $intercept_{(T)}$ are parameters given in Table 11.2.

In IPCC 2019, in addition to the above equation, an alternate method to determine $AG_{DM(T)}$ is made available:

$$AG_{DM(T)} = Crop_{(T)} \times R_{AG(T)}$$

Where $R_{AG(T)}$ is a parameter given in Table 11.A.

In the updated model, the latter method is preferred because, as $Crop_{(T)}$ is directly calculated in kg d.m. instead of kg d.m. ha$^{-1}$, using the first method would require to adjust the values of $intercept_{(T)}$ by adapting the units.

The change in method to determine $AG_{DM(T)}$ leads to an increase of the estimation of the N content.

## 3.2 Other technical adjustments

In the previous version of the model, the combustion factor $C_f$ is omitted in the implementation of Equation 11.6. This leads to an underestimation of the N content in crop residues. As the updated model includes the combustion factor, the calculated values for the N content are higher for the crop types that have a share burnt.

In addition, in the previous version of the model, the share of area burnt was applied to both above and below-ground residues. The updated model applies the share of area burnt only to the above-ground residues as per equation 11.6 of IPCC 2006, leading to an increase in the estimation of the total N content.

## References

Aalde et al., "2006 IPCC Guidelines for National Greenhouse Gas Inventories". *Volume 4: Agriculture, Forestry and Other Land Use. Chapter 2: Generic methodologies applicable to multiple land-use categories*. 2006. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

De Klein et al., "2006 IPCC Guidelines for National Greenhouse Gas Inventories". *Volume 4: Agriculture, Forestry and Other Land Use. Chapter 11: $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application*. 2006. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Grønlund et al., "Nitrogen i restavlinger Oppdatering av koeffisienter for beregning av lystgass fra restavlinger". *Bioforsk rapport*. 2014

Hergoualc'h et al., "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories". *Volume 4: Agriculture, Forestry and Other Land Use*. *Chapter 11: $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application*. 2019. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Hutchings et al., "EMEP/EEA air pollutant emission inventory guidebook 2019". *Chapter 3.D Agricultural soils*. 2023. Retrieved from: https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/3-agriculture/3-d-agricultural-soils-2023/view

SLF, "Vurdering av omfang av halmbrenning pr 2011". 201. Notat fra Statens landsbruksforvaltning.

# Appendix

## A. Values of parameters

Table 4 – Values of the dry matter fraction of harvested crop for each crop type. Values noted "IPCC 2019" are taken from Table 11.1A of IPCC 2019. Values noted "National factor (Bioforsk report)" are taken from Grønlund et al. (2014).

| Crop type | $DRY_{(T)}$ (kg d.m. (kg fresh weight)$^{-1}$) | Origin of the value |
|---|---|---|
| Perennial grass | 0.90 | IPCC 2019 |
| Grass-clover mixtures | 0.90 | IPCC 2019 |
| Wheat | 0.85 | National factor (Bioforsk report) |
| Rye | 0.85 | National factor (Bioforsk report) |
| Triticale | 0.85 | National factor (Bioforsk report) |
| Barley | 0.85 | National factor (Bioforsk report) |
| Oat | 0.85 | National factor (Bioforsk report) |
| Oil seeds | 0.85 | National factor (Bioforsk report) |
| Potatoes | 0.22 | IPCC 2019 |
| Tubers | 0.22 | IPCC 2019 |
| Green forages | 0.90 | IPCC 2019 |
| Vegetables | 0.22 | IPCC 2019 |
| Peas | 0.91 | IPCC 2019 |
| Beans | 0.91 | IPCC 2019 |

Table 5 – Values of the ratio of above-ground residue dry matter to harvested yield for each crop type. Values noted "IPCC 2019" are taken from Table 11.1A of IPCC 2019. Values noted "National factor (Bioforsk report)" are taken from Grønlund et al. (2014).

| Crop type | $R_{AG(T)}$ (kg d.m. (kg d.m.)$^{-1}$) | Origin of the value |
|---|---|---|
| Perennial grass | 0.30 | IPCC 2019 |
| Grass-clover mixtures | 0.30 | IPCC 2019 |
| Wheat | 0.95 | National factor (Bioforsk report) |
| Rye | 1.10 | National factor (Bioforsk report) |
| Triticale | 1.30 | IPCC 2019 |
| Barley | 1.20 | IPCC 2019 |
| Oat | 1.30 | IPCC 2019 |
| Oil seeds | 1.30 | IPCC 2019 |
| Potatoes | 0.40 | IPCC 2019 |
| Tubers | 0.40 | IPCC 2019 |
| Green forages | 0.30 | IPCC 2019 |
| Vegetables | 0.40 | IPCC 2019 |
| Peas | 2.10 | IPCC 2019 |
| Beans | 2.10 | IPCC 2019 |

Table 6 – Values of the fraction of above-ground residues of crop removed annually for purposes such as feed, bedding and construction ($Frac_{Remove(T)}$). Values from an interview with expert Tore Krogstad (2005).

| Crop type | Value 1990 - 2000 | Value 2001 - 2021 |
|---|---|---|
| Wheat, Rye, Triticale, Barley, Oat | 15% | 13% |
| Oil seeds | 15% | 15% |
| Other | 0% | 0% |

Table 7 – Fraction of annual harvested area burnt for each crop ($Frac_{Burnt(T)}$). Values are taken from a note by Statens landsbruksforvaltning (2011).

| Years | Value for wheat, rye, triticale, barley, oat and oil seeds | Value for others |
|---|---|---|
| 1990 | 30% | 0% |
| 1991 | 25% | 0% |
| 1992-1996 | 20% | 0% |
| 1997-2000 | 15% | 0% |
| 2001 | 12.5% | 0% |
| 2002 | 10% | 0% |
| 2003-2004 | 7.5% | 0% |
| 2005 | 7% | 0% |
| 2006 | 6.5% | 0% |
| 2007 | 6% | 0% |
| 2008 | 5.5% | 0% |
| 2009 | 5% | 0% |
| 2010 | 4.5% | 0% |
| 2011-2021 | 4% | 0% |

Table 8 – Values of the combustion factor for each crop type. Values are extracted from Table 2.6 of IPCC 2019[10]. The combustion factor is not applicable when there are no burnt residues.

| Crop type | $C_{f(T)}$ |
|---|---|
| Perennial grass | Non applicable |

[10] Aalde et al., "2006 IPCC Guidelines for National Greenhouse Gas Inventories". *Volume 4: Agriculture, Forestry and Other Land Use. Chapter 2: Generic methodologies applicable to multiple land-use categories*. 2006. Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

| | |
|---|---|
| Grass-clover mixtures | Non applicable |
| Wheat | 0.90 |
| Rye | 0.85 (assumed "Other crops") |
| Triticale | 0.90 (assumed "Wheat") |
| Barley | 0.85 (assumed "Other crops") |
| Oat | 0.85 (assumed "Other crops") |
| Oil seeds | 0.85 (assumed "Other crops") |
| Potatoes | Non applicable |
| Tubers | Non applicable |
| Green forages | Non applicable |
| Vegetables | Non applicable |
| Peas | Non applicable |
| Beans | Non applicable |

Table 9 – Values for the ratio of below-ground root biomass to above-ground shoot biomass for each crop type. Values are extracted from the Bioforsk rapport.

| Crop type | $RS_{(T)}$ (kg d.m. (kg d.m.)$^{-1}$) |
|---|---|
| Perennial grass | 0.80 |
| Grass-clover mixtures | 0.80 |
| Wheat | 0.24 |
| Rye | 0.22 |
| Triticale | 0.23 |
| Barley | 0.22 |
| Oat | 0.25 |

| | |
|---|---|
| Oil seeds | 0.22 |
| Potatoes | 0.20 |
| Tubers | 0.20 |
| Green forages | 0.54 |
| Vegetables | 0.20 |
| Peas | 0.19 |
| Beans | 0.19 |

Table 10 – Values of the N content of above-ground residues for each crop type. Values noted "IPCC 2019" are taken from Table 11.1A of IPCC 2019. Values noted "National factor (Bioforsk report)" are taken from Grønlund et al. (2014).

| Crop type | $N_{AG(T)}$ (kg N (kg d.m.)$^{-1}$) | Origin of the value |
|---|---|---|
| Perennial grass | 0.0150 | National factor (Bioforsk report) |
| Grass-clover mixtures | 0.0190 | National factor (Bioforsk report) |
| Wheat | 0.0042 | National factor (Bioforsk report) |
| Rye | 0.0050 | IPCC 2019 |
| Triticale | 0.0060 | IPCC 2019 |
| Barley | 0.0050 | National factor (Bioforsk report) |
| Oat | 0.0033 | National factor (Bioforsk report) |
| Oil seeds | 0.0060 | National factor (Bioforsk report) |
| Potatoes | 0.0190 | IPCC 2019 |
| Tubers | 0.0190 | IPCC 2019 |
| Green forages | 0.0150 | IPCC 2019 |
| Vegetables | 0.0190 | IPCC 2019 |
| Peas | 0.0080 | IPCC 2019 |

| | | |
|---|---|---|
| Beans | 0.0080 | IPCC 2019 |

Table 11 – Values of the N content of below-ground residues for each crop type. Values noted "IPCC 2019" are taken from Table 11.1A of IPCC 2019. Values noted "National factor (Bioforsk report)" are taken from Grønlund et al. (2014).

| Crop type | $N_{BG(T)}$ (kg N (kg d.m.)$^{-1}$) | Origin of the value |
|---|---|---|
| Perennial grass | 0.0110 | National factor (Bioforsk report) |
| Grass-clover mixtures | 0.0130 | National factor (Bioforsk report) |
| Wheat | 0.0090 | National factor (Bioforsk report) |
| Rye | 0.0110 | IPCC 2019 |
| Triticale | 0.0090 | IPCC 2019 |
| Barley | 0.0140 | IPCC 2019 |
| Oat | 0.0080 | IPCC 2019 |
| Oil seeds | 0.0090 | IPCC 2019 |
| Potatoes | 0.0140 | IPCC 2019 |
| Tubers | 0.0140 | IPCC 2019 |
| Green forages | 0.0120 | IPCC 2019 |
| Vegetables | 0.0140 | IPCC 2019 |
| Peas | 0.0080 | IPCC 2019 |
| Beans | 0.0080 | IPCC 2019 |

## B. Comparison of Equations 11.6 in IPCC 2006 and IPCC 2019

In the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Equation 11.6 that was used to estimate the N content in crop residues was:

$$F_{CR} = \sum_{T} \{Crop_{(T)} \times Frac_{Renew(T)} \times \left[(Area_{(T)} - Frac_{Burnt(T)} \times C_f) \times R_{AG(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)}) + (Area_{(T)} \times R_{BG(T)} \times N_{BG(T)}\right]\}$$

In the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories,* Equation 11.6 was updated to:

$$F_{CR} = \sum_{T} \{[AGR_{(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)} - (Frac_{Burnt(T)} \times C_f))] + [BGR_{(T)} \times N_{BG(T)}]\}$$

This section compares the two equations to evaluate the impacts the update may have on the results.

In all the following calculations, the N content of a single crop type is examined. Therefore, the subscript *(T)* is omitted for simplicity.

According to IPCC 2006, the N content of crop residues is:

$$F_{CR\_2006} = Crop \times Frac_{renew} \times \left[\left(Area - Area_{burnt} \times C_f\right) \times R_{AG} \times N_{AG} \times (1 - Frac_{remove}) + Area \times R_{BG} \times N_{BG}\right]$$

And according to IPCC 2019, the same quantity is:

$$F_{CR\_2019} = AGR \times N_{AG} \times \left(1 - Frac_{remove} - Frac_{burnt} \times C_f\right) + BGR \times N_{BG}$$

Considering that:

$Area$ = total annual area harvested, as per IPCC 2006 and IPCC 2019

$Area_{burnt}$ = annual area of crop burnt, as per IPCC 2006

$Frac_{burnt}$ = fraction of annual harvested area of crop burnt, as per IPCC 2019

It can be deduced that $Area_{burnt} = Area \times Frac_{burnt}$ assuming that there is no crop area that is burnt without being harvested.

And, as per IPCC 2006, $R_{BG} = \frac{AG_{DM}+Crop}{Crop}$, assuming that $AG_{DM}$ is expressed[11] in kg d.m. ha$^{-1}$

Thus:

$$F_{CR\_2006} = Crop \times R_{AG} \times F_{renew} \times N_{AG} \times (1 - Frac_{remove}) \times Area \times \left(1 - Frac_{burnt} \times C_f\right) + Crop \times Frac_{renew} \times Area \times \frac{AG_{DM} + Crop}{Crop} \times R_{BG-BIO} \times N_{BG}$$

With:

[11] $AG_{DM}$ is calculated in ton d.m. ha$^{-1}$ in IPCC 2006 thus making a factor 1000 appear in the expression, not reported here.

$AG_{DM}$ = $Crop \times R_{AG}$ , as per IPCC 2019

$BGR$ = $(Crop + AG_{DM}) \times RS \times Area \times Frac_{renew}$, as per IPCC 2019

Thus:

$$F_{CR\_2006} = AG_{DM} \times Frac_{renew} \times Area \times N_{AG} \times (1 - Frac_{remove})(1 - Frac_{burnt} \times C_f) + BGR \times \frac{R_{BG-BIO}}{RS} \times N_{BG}$$

With $R_{BG-BIO} = RS$ by comparison of definition and tables in IPCC 2006 and 2019. Hence:

$$F_{CR\_2006} = AG_{DM} \times Frac_{renew} \times Area \times N_{AG} \times (1 - Frac_{remove} - Frac_{burnt} \times C_f + Frac_{remove} \times Frac_{burnt} \times C_f) + BGR \times N_{BG}$$

At this point, it can be observed that $F_{CR\_2006}$ and $F_{CR\_2019}$ have the same expression for the N content of below-ground residues ($BGR \times N_{BG}$).

By comparison of the expressions of $F_{CR\_2006}$ and $F_{CR\_2019}$, and by similarity to $BGR$, it can be inferred that: $AGR = AG_{DM} \times Area \times Frac_{renew}$.

Thus:

$$F_{CR\_2006} = AGR \times N_{AG} \times (1 - Frac_{remove} - Frac_{burnt} \times C_f + Frac_{remove} \times Frac_{burnt} \times C_f) + BGR \times N_{BG}$$

The difference between $F_{CR\_2006}$ and $F_{CR\_2019}$ is that $F_{CR\_2006}$ has an additional term $Frac_{remove} \times Frac_{burnt} \times C_f$ for the N content in above-ground residues. This only impacts the results for crops that have straw-like residues. For the other types of crops, $Frac_{remove} = Frac_{burnt} = 0$ and there is no difference between the two equations.

Table 12 – Impact of the difference in expression of the N content of above-ground residues between Equation 11.6 in IPCC 2006 and Equation 11.6 in IPCC 2019. The values are given for wheat.

| Parameter | 1990 | 2000 | 2020 |
|---|---|---|---|
| $\boldsymbol{Frac_{remove}}$ | 15% | 15% | 13% |
| $\boldsymbol{Frac_{burnt}}$ | 30% | 15% | 4% |
| $\boldsymbol{C_f}$ | 0.9 | 0.9 | 0.9 |
| $\boldsymbol{1 - Frac_{remove} - Frac_{burnt} \times C_f}$ | 58% | 71.5% | 83.4% |
| $\boldsymbol{1 - Frac_{remove} - Frac_{burnt} \times C_f + Frac_{remove} \times Frac_{burnt} \times C_f}$ | 62.05% | 73.53% | 83.87% |
| $\boldsymbol{\frac{1 - Frac_{remove} - Frac_{burnt} \times C_f + Frac_{remove} \times Frac_{burnt} \times C_f}{1 - Frac_{remove} - Frac_{burnt} \times C_f}}$ | 1.07 | 1.03 | 1.01 |

As displayed in Table 12, the estimation of N content in (straw-like) above-ground residues is 1 to 7% larger with the Equation 11.6 from IPCC 2006 than with the Equation 11.6 from IPCC 2019. The smallest the fraction of the area burnt, the smaller the difference.

Equation 11.6 in IPCC 2019 is mostly a re-writing of Equation 11.6 in IPCC 2006 with changes in notations. However, due to the change in expression, the estimation of N content in above-ground residues is slightly lower, for some crops, using the updated version of Equation 11.6 compared to the previous one.

CARBON LIMITS

October 2023

Carbon Limits AS
@CarbonLimitsAS

CJ Hambros plass 2
0164 Oslo
Norge

+47 988 457 930
www.carbonlimits.no