Study for the development of a common framework for the quantitative advice of crop nutrient requirements and greenhouse gas emissions and removal assessment at farm level

AGRI-2020-0316 ("FaST Navigator")

Study report – Annex:

Details of methodology for the GHG framework

Susanne Köppen
IFEU (Institut für Energie- und Umweltforschung, Heidelberg, Germany)

Table of contents

List of tables

1. The greenhouse gas calculation methodology

1.1 System boundaries

The spatial unit for the greenhouse gas (GHG) calculation is the farm. The methodology follows a life cycle based approach where all emissions are taken into account starting with upstream emissions up to the production of agricultural goods (`cradle-to-gate`). The emissions cover direct emissions occuring at farm level (A) and indirect upstream emissions ocurring from the production and distribution of energy and materials (B). The calculation includes all parts of a farm, namely crop production, livestock farming, carbon stocks and carbon stock changes as well as energy use (see Figure 1). Besides direct and indirect emissions carbon sinks in biomass and soil are taken into account. The balancing of emissions and removals lead to net GHG emissions at farm level.

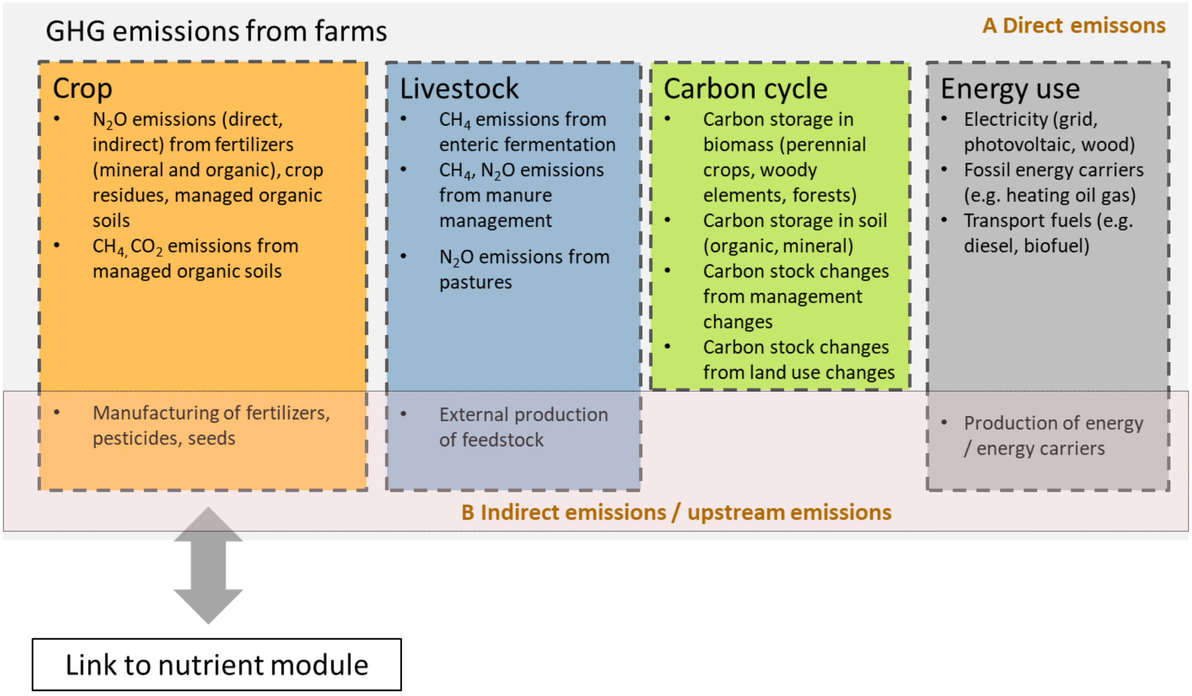

Figure 1. Overview framework for GHG calculation

The time reference period for the calculation and the reporting is one numerical year.

The following elements are <u>not</u> included:

- Construction of infrastructure (buildings, roads)
- Materials (e.g. packaging, fences)
- Processing and distribution of agricultural products at the farm or outside the farm

1.2 Emission sources

The methodology covers the three key greenhouse gases for agriculture: carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O). The GHG emissions and removals are calculated for each gas separately and, at the end, converted into CO_2 equivalents (CO_{2eq}) based on the Global Warming Potential (GWP) of each gas. The GWPs are based on the 2007 IPCC report (Climate Change 2007):

- 1 t CO_2 = 1 t CO_{2eq}
- 1 t CH_4 = 25 t CO_{2eq}

- 1 t N_2O = 298 t CO_{2eq}

The methodology considers the following emission sources:

- Soil emissoins (direct and indirect N_2O emissions; CO_2, N_2O and CH_4 emissions from drained organic soils);
- Livestock emissions (CH_4 and N_2O emissions from enteric fermentation and manure management);
- Energy use emissions (direct and indirect CO_2 emissions);
- Other upstream emissions (indirect CO_2 emissions from production of materials);
- Changes in carbon stocks (CO_2) in soils, natural infrastrcture and forests due to managemen and land use changes

1.3 Principles of GHG calculation and time frame

The greenhouse gas emissions (E) at farm level are calculated based on the following equation:

$E = AD \cdot EF$

where AD is the activity data and EF the emission factor.

Activity data occur from all activities at farm level. They cover, among others, the amount of fertilizers applied, the number and type of animals, the share of organic soils, the amount of diesel used for field works, the number and size of natural elements. The type and amount of data may change according to the line applied and are detailed in the following sections. These data have to be collected and filled in by the farmer. The temporal reference is one numerical year.

Emission factors are the emissions associated with the above mentioned activities. They can occur from fertilizer use, livestock management (e.g. methane emissions from enteric fermentation, manure storage emissions) as well as from the production and use of agricultural inputs (e.g. fertilizers, transport fuels, animal feedstocks). The following sections list all emission factors and their sources.

1.4 Geographical scope

The GHG methodology is strongly linked to the nutrient module and covers a wide range of climatic conditions and soil types. Moreover, it includes a wide range of crop types, livestock types (at different levels of milk yields) and housing options. Since the farmer fills in yields, fertilizer amounts, livestock numbers etc. the results represent the main farm types and environmental conditions at EU-27 level. Where possible, emission factors are adapted to different environmental conditions. Details are provided in the following sections.

1.5 Fields of applications and limitations

The FAST Navigator is able to reflect GHG emission changes that arise from optimising farm management practices. When a farmer changes his management practices, this will lead to lower or higher emissions compared with the practices of a previous year. Since the tool displays the status quo, in most cases it does not present these emission changes directly (exception: changes in soil organic carbon, see section on carbon cycle). However, a farmer may use the tool to model emission changes by calculating emissions from his current status quo and those after applying certain management changes. Moreover, he may compare the results from subsequent years.

1.6 Differentiation into lines and future improvements

The **proposed Navigator framework** integrates different lines which have been dubbed G1, G2, G3, G4 (G stands for greenhouse gases). The main methodology used is based on the IPCC Guidelines. A review of around 90 farm level tools methodologies and data bases revealed that these are the most widely used reference for application at farm level.The IPCC method was adapted for use at farm level and supplemented by additional methods. For the standard values, IPCC values were also used in part, and other databases and scientific literature were used in part. The applied methods and data sources are described in detail in the subsequent sections. Within this general methodological framework, the lines differ regarding the level of detail of data collection by the farmer. Beginning at line G4 up to line G1, default values are increasingly replaced by models and / or own values. In order to keep the data load as low as possible, the level of differentiation is based on the influence of the individual elements on the total emissions, or on the political relevance. For example, in livestock, emissions from digestion are more disaggregated (three levels of detail), while emissions from manure management and storage are less differentiated. Other foci are on soil N_2O emissions and on the potential for carbon accumulation in mineral soils due to management changes. In all elements, however, own values can always be entered by the user in level G1. Especially the livestock sector would offer the possibility to get a higher degree of accuracy by introducing more detailed models and methods, for example by considering the influence of feeding on digestion emissions (according to the IPCC Tier 2 approach). However, a trade-off must be made between the accuracy of the tool and the data load for the user.

In terms of **future development of the framework**, the line G4 could be replaced by a simpler approach than those described here. This involves deriving national emission factors from national inventory reports as part of climate reporting. For example, a factor for methane emissions from digestion can be derived as follows: national methane emissions from digestion are divided by the number of ruminants in the country to obtain a per livestock head emission factor. This can be stored in the tool so that the user only has to enter the number of ruminants. Here, too, there is the possibility of further differentiation, for example by deriving an emission factor specifically for cattle. However, this requires sufficient differentiation of the inventory reports.

Another possible adjustment exists at the level of emission factors as well as other default values. These differentiate little or not at all between environmental and production factors in individual EU member states. If possible, these can be replaced by national, or even regional, emission factors when applying the framework in individual countries. A suitable source for this are again national inventory reports, or their corresponding preparatory work such as scientific publications.

2. Crop production

Emissions from crop production cover the following sources:

- Direct and indirect N_2O emissions from the use of
  - Synthetic N fertilisers
  - Organic N fertilisers (e.g. manure, digestate, compost, sewage sludge)
  - Crop residues (above and below ground)
- N2O, CH_4 and CO_2 emissions from the drainage / management of organic soils

The calculation of GHG emissions in crop production is strongly linked to the nutrient balance covered by the nutrient module. The relevant links and overlaps are detailed in the following sections. A differentiation between the lines is only applied on the mineral fertilizer use on mineral soils.

2.1 Direct N_2O emissions from the use of fertilisers and from residues

Direct N_2O emissions occur when nitrogen is added to soils (e.g. through the use of mineral or organic fertilisers or from crop residues) or due to N mineralisation induced by land use or land management changes. If nitrogen is added to the soil, the increase in N amount leads to nitrification and denitrification rates.

The calculation is based on equation 11.1 (IPCC 2006, chapter 11):

$N_2O_{direct}\text{-}N = N_2O\text{-}N_{N\ inputs} + N_2O\text{-}N_{OS}$

$N_2O\text{-}N_{N\ inputs} = [F_{SN} + F_{ON} + F_{CR}) \times EF_1)$

- $N_2O_{direct}\text{-}N$ = annual direct N_2O–N emissions produced from managed soils (kg N_2O-N /year)
- $N_2O\text{-}N_{N\ inputs}$ = annual direct N_2O–N emissions from N inputs to managed soils (kg N_2O-N/year)
- F_{SN} = annual amount of synthetic fertiliser N applied to soils (kg N / year)
- F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N / year)
- F_{CR} = annual amount of N in crop residues (above-ground and below-ground (kg N / year)
- EF_1 = emission factor for N_2O emissions from N inputs (kg N_2O–N / kg N input)

Direct and indirect N_2O emissions from urine and dung placed on pastures by grazing animals (N_2O–N_{PRP}) is integrated in the livestock part (see chapter 3).

2.1.1 Emissions from fertilizer application

The application of mineral and organic fertilisers (e.g. manure, digestate, sewage sludge, compost) is the main source of N additions. The farmer has to fill in information on the type and amount of fertilizer applied. The Navigator uses two different sets of emission factors (EF_1) in line G4/G3 and G2/G1.

2.1.1.1 Fertilizer emissions - line G3 and G4

Since the type of mineral fertlizer applied is known by the farmers, the methodology uses specific emission factors for certain fertiliser types. All other emission factors use the IPCC 2006 Tier 1 emission factor. Table 1 shows the emission factors used for mineral and organic fertilisers (EF_1).

Table 1 Emission factors for direct N_2O emissions from fertilizer application (EF_1)

Fertilizer type	**Emission factor (EF_1) [kg N_2O-N / kg N]**	**Source**
Mineral fertilizers		
Ammonium nitrate	0.007	Bouwman et al. 2002
Ammonium nitrate 33%	0.007	Bouwman et al. 2002
Ammonium nitrate 27% (NAC)	0.007	Bouwman et al. 2002
Ammonium nitrate 20%	0.007	Bouwman et al. 2002
Sodium nitrate	0.007	Bouwman et al. 2002
Potassium nitrate	0.007	Bouwman et al. 2002
Nitrophosphates	0.007	Bouwman et al. 2002
Nitric acid	0.007	Bouwman et al. 2002

Complex	0.007	Bouwman et al. 2002
Suspension	0.007	Bouwman et al. 2002
Mono-ammonium phosphate (MAP)	0.01	IPCC 2006 (chapter 11, table 11.1)
Di-ammonium phosphate (DAP)	0.01	IPCC 2006 (chapter 11, table 11.1)
Ammonium polyphosphates (APP)	0.01	IPCC 2006 (chapter 11, table 11.1)
Ammonium sulphate	0.011	Bouwman et al. 2002
Ammonium nitrophosphate 26%	0.011	Bouwman et al. 2002
Ammonium nitrophosphate 21%	0.011	Bouwman et al. 2002
Magnesium sulfate	0.011	Bouwman et al. 2002
Ammonium sulfate 21%	0.011	Bouwman et al. 2002
Ammonium nitrosulphate	0.01	IPCC 2006 (chapter 11, table 11.1)
Calcium ammonium nitrate	0.01	IPCC 2006 (chapter 11, table 11.1)
Calcium nitrate	0.01	IPCC 2006 (chapter 11, table 11.1)
Magnesium nitrate	0.01	IPCC 2006 (chapter 11, table 11.1)
Complex 15-15-15	0.01	IPCC 2006 (chapter 11, table 11.1)
Urea	0.011	Bouwman et al. 2002
Urea formaldehyde (UF)	0.011	Bouwman et al. 2002
Isobutylidene diurea (IBDU)	0.011	Bouwman et al. 2002
Crotonylidene diurea (CDU)	0.011	Bouwman et al. 2002
Urea 46%	0.011	Bouwman et al. 2002
Urea 46%+ Inhibidor	0.011	Bouwman et al. 2002
Urea 40%+ Azufre (YARA Sulfamid)	0.011	Bouwman et al. 2002
Nitro33	0.011	Bouwman et al. 2002
Nitroplus	0.011	Bouwman et al. 2002
Nitrogen solutions (32%)	0.011	Bouwman et al. 2002
Calcium nitrate solution	0.011	Bouwman et al. 2002
Magnesium nitrate solution	0.011	Bouwman et al. 2002
Organic fertiliser	0.01	IPCC 2006 (chapter 11, table 11.1)

2.1.1.2 Fertilizer emissions - line G2 and G1

For direct N_2O emissions on mineral soils, the IPCC Tier 1 emission factor (EF_1) is disaggregated taking into account differences in management and environmental conditions. The Tier 2 emission factors is based on the fertilizer induced emission (FIE) concept developed by Stehfest and Bouwman (2006). For further details on the methodoly and its application at European level, see also JRC 2014. For each specific crop, the emissions are calculated based on the following equation:

$$EF_1 = \exp(c + 0.0038 * (F_{SN} + F_{ON}) + ev_{soc} + ev_{ph} + ev_{tex} + ev_{clim} + ev_{veg} + ev_{expl}) - \exp(c + ev_{soc} + ev_{ph} + ev_{tex} + ev_{clim} + ev_{veg} + ev_{expl})$$

Table 2 shows the constant and effect values applied (Stehfest and Bouwman (2006), Smeets et al. 2009).

Table 2. Constant and effect values applied for calculating fertilizer induced N_2O emissions

Value type		Value
Constant value c		-1,516
Fertilizer input		0.0038 x kg N input
Soil organic carbon content (ev_{SOC})	<1%	0
	1-3%	0.0526
	>3%	0.6334
pH (ev_{pH})	<5,5%	0
	5,5-7,3%	-0.0693
	>7,3%	-0.4836
Soil texture (ev_{tex})	Coarse	0
	Medium	-0.1528
	Fine	0.4312
Climate (ev_{clim})	temperate continental	0
Vegetation (ev_{veg})	Cereal	0
	grass	-0.3502
	legume	0.3783
	rice	-0.885
	other	0.442
Length (ev_{expl})	1 year	1.991

The information regarding soil organic carbon content, pH, soil texture and climate is linked to the nutrient module.

2.1.2 Emissions from crop residues (line G4 – G1)

Crop residues contribute to the increase of N content in soils and thus lead to N_2O emissions, similar to fertiliser application. The calculation includes above and below ground residues.

The emission factor is 0.01 kg N_2O-N / kg N (IPCC 2006, chapter 11, table 11.1) for all types of crop residues.

The amount of N from crops residues is calculated based on IPCC 2019 Tier 1 (equation 11.6):

$F_{CR} = AGR \times N_{AG} \times (1- Frac_{Remove}) + BGR \times N_{BG})$

$BGR = (Crop + AG_{DM}) \times RS \times Area \times Frac_{Renew}$

$AG_{DM} = Crop \times R_{AG}$

- F_{CR}: annual amount of N in crop residues (above and below ground) (kg N / year)
- AGR: annual total amount of above-ground crop residue (kg dm / year)
- N_{AG}: N content of above-ground residues (kg N / kg dm) ➔ see table 11.1A (IPCC 2019)
- $Frac_{Remove}$: fraction of above-ground residues of crop T removed annually (dimensionless) ➔ to be filled in by farmer (either “removed” or “ incorporated”)
- BGR: annual total amount of belowground crop residue (kg dm / year)
- N_{BG}: N content of below-ground residues (kg N / kg dm) ➔ see table 11.1A (IPCC 2019)

- AG_{DM}: = Above-ground residue dry matter (kg dm/ ha); calculated as follows: Crop x Slope+ Intecept → table 11.2 (IPCC 2019)
- Crop: harvested annual dry matter yield (kg dm/ ha) → to be included by farmer
- R_{AG} : ratio of above-ground residue dry matter to harvested yield (kg dm / kg dm) → see table 11.1A (IPCC 2019)
- Area: total annual area harvested (ha / year) → to be included by farmer
- FracRenew: fraction of total area that is renewed annually → for annual crops = 1
- RS: ratio of below-ground root biomass to above-ground shoot biomass (kg dm / kg dm) → see table 11.1A (IPCC 2019)

The Navigator the above metioned default values for 115 different annual crops.

The Navigator does not take into account burnt crop residues.

2.2 Indirect N_2O emissions from the use of fertilisers and from residues (lines G4 – G1)

Indirect N_2O emissions occur from two different pathways. First, N volatilization releases NH_3 and NO_x followed by the redeposition of these gases and their products (NH_4^+ and NO_3^-). These gases trigger indirect N_2O emissions at the site of atmospheric deposition. Secondly, NO_3^- leaching from agricultural soils into water bodies leads to indirect N_2O emissions. The amount of N going to volatilisation, leaching and runoff is calculated by the nutrient module and passed to the GHG module. There, the eventual N_2O emissions are calculated based on the following Tier 1 emission factors.

Table 3. Emission factors for indirect N_2O emissions

	Emission factor [kg N_2O-N / kg N]	**Source**
Volatilisation	0.01	IPCC 2006 (chapter 11, table 11.3)
Leaching and runoff	0.0075	IPCC 2006 (chapter 11, table 11.3)

2.3 Emissions from drained and managed organic soils (line G4 – G1)

The drainage and management of organic soils causes three types of emissions that are included in the Navigator:

- carbon dioxide (CO_2) emissions
- methane (CH_4) emissions
- nitrous oxide (N_2O) emissions

The methodology follows the IPCC 2013 wetland supplement.

Carbon dioxide (CO_2) emissions take into account on-site carbon emissions and emissions from dissolved organic carbon (DOC) exported from the drained organic soils (see equation 2.2, IPCC 2013):

$CO_2\text{-}C_{organic,\ drained} = CO_2\text{-}C_{on\text{-}site} + CO_2\text{-}C_{DOC}$

- CO_2-$C_{organic, drained}$ = CO_2-C emissions/removals by drained organic soils (t C / year)
- CO_2-$C_{on\text{-}site}$ = on-site CO_2-C emissions/removals by drained organic soils (t C / year)
- CO_2-C_{DOC} = CO_2-C emissions from dissolved organic carbon (DOC) exported from drained organic soils (t C / year)

The emission factors for on-site emissions are summarized in Table 4.

Table 4. Emission factors for on-site emissions in managed organic soils

Management type	Emission factor on-site emissions [t CO_2-C / ha]	Source
Cropland	7.9	IPCC 2013 Table 2.1
Grassland	5.18	IPCC 2013 Table 2.1 (average of all grassland types)

The emission factors for DOC emissions are summarized in Table 5.

Table 5. Emission factors for DOC emissions in managed organic soils

Climate regime	Emission factor DOC emissions [t CO_2-C / ha]	Source
temperate	0.31	IPCC 2013 Table 2.2
boreal	0.12	IPCC 2013 Table 2.2

Furthermore, **CH_4 emissions** are taken into account based on equation 2.6:

$CH_{4\_organic} = A \times EF_{CH4\_land}$

$CH_{4\_organic}$: annual CH_4 loss from drained organic soils (kg CH_4 / year)

A: land area of drained organic soils

EF_{CH4_land}: emission factors for direct CH_4 emissions from drained organic soils (kg CH_4 / ha / year)

The CH_4 emissions are only taken into account for grassland since for drained cropland in boreal and temerate climates the emission factor is 0. For grasslands an average value across the different types has been calculated and the factor is 14.1 kg CH_4 / ha (IPCC 2013 table 2.3).

The third category are **N_2O emissions** which are displayed in Table 6, based on the following formula:

$N_2O\text{-}N_{OS} = F_{OS} \text{ X } EF_2$

- $N_2O\text{-}N_{OS}$ = annual direct N_2O–N emissions from managed organic soils (kg N_2O–N / year)
- F_{OS} = annual area of managed/drained organic soils (ha)
- EF_2 = emission factor for N_2O emissions from drained/managed organic soils (kg N_2O–N / kg N input)

Table 6. Emission factors for N_2O emissions in managed organic soils

Climate regime	Emission factor N_2O emissions [kg N_2O-N / ha]	Source
Cropland	13	IPCC 2013 Table 2.5
Grassland	5.9	IPCC 2013 Table 2.5 (average of all grassland types)

2.4 Upstream emissions for crop production

This section provides the indirect emissions from producing and transporting inputs used on the farm. Agricultural inputs presented in this section includes production of fertilisers, seeds, pesticides and transport fuels for field work. Other energy input are summarizes under section 5. Table 7 lists all upstream emissions for agricultural inputs.

Table 7 Emission factors for input upstream emissions

Fertilizer type	Emission factor [g CO_{2equ} / kg]	Source
N-Fertilizers		
Ammonium nitrate	3468.66	Brentrup & Pallière 2014
Ammonium nitrate 33%	3468.66	Brentrup & Pallière 2014
Ammonium nitrate 27% (NAC)	3468.66	Brentrup & Pallière 2014
Ammonium nitrate 20%	3468.66	Brentrup & Pallière 2014
Sodium nitrate	3468.66	Brentrup & Pallière 2014
Potassium nitrate	3468.66	Brentrup & Pallière 2014
Nitrophosphates	3468.66	Brentrup & Pallière 2014
Nitric acid	3468.66	Brentrup & Pallière 2014
Complex	3468.66	Brentrup & Pallière 2014
Suspension	3468.66	Brentrup & Pallière 2014
Mono-ammonium phosphate (MAP)	1028.85	Brentrup & Pallière 2014
Di-ammonium phosphate (DAP)	1544.72	Brentrup & Pallière 2014
Ammonium polyphosphates (APP)	1544.72	Brentrup & Pallière 2014
Ammonium sulphate	2723.81	Brentrup & Pallière 2014
Ammonium nitrophosphate 26%	2723.81	Brentrup & Pallière 2014
Ammonium nitrophosphate 21%	2723.81	Brentrup & Pallière 2014
Magnesium sulfate	2723.81	Brentrup & Pallière 2014
Ammonium sulfate 21%	2723.81	Brentrup & Pallière 2014
Ammonium nitrosulphate	3161.54	Brentrup & Pallière 2014
Calcium ammonium nitrate	3670.37	Brentrup & Pallière 2014
Calcium nitrate	4348.39	Brentrup & Pallière 2014
Magnesium nitrate	4348.39	Brentrup & Pallière 2014
Complex 15-15-15	5013.33	Brentrup & Pallière 2014
Urea	3509.69	Brentrup & Pallière 2014

Urea formaldehyde (UF)	3509.69	Brentrup & Pallière 2014
Isobutylidene diurea (IBDU)	3509.69	Brentrup & Pallière 2014
Crotonylidene diurea (CDU)	3509.69	Brentrup & Pallière 2014
Urea 46%	3509.69	Brentrup & Pallière 2014
Urea 46%+ Inhibidor	3509.69	Brentrup & Pallière 2014
Urea 40%+ Azufre (YARA Sulfamid)	3509.69	Brentrup & Pallière 2014
Nitro33	3509.69	Brentrup & Pallière 2014
Nitroplus	3509.69	Brentrup & Pallière 2014
Nitrogen solutions (32%)	3509.69	Brentrup & Pallière 2014
Calcium nitrate solution	3670.37	Brentrup & Pallière 2014
Magnesium nitrate solution	3509.69	Brentrup & Pallière 2014
K2O fertilizers		
Potassium chloride	413.33	Brentrup & Pallière 2014
Potassium sulphate	413.33	Brentrup & Pallière 2014
Potassium phosphates	413.33	Brentrup & Pallière 2014
P2SO5 fertilizers		
Triple superphosphate (TSP)	541.97	JRC 2019
Superphosphate simple	541.97	JRC 2019
Superphosphate concentrate	541.97	JRC 2019
Phosphoric acid	541.97	JRC 2019
Superphosphoric acid	541.97	JRC 2019
Dycalcium phosphate	541.97	JRC 2019
Calcium metaphosphate	541.97	JRC 2019
Calcined phosphate	541.97	JRC 2019
Basic slags	541.97	JRC 2019
Superphosphate 18%	541.97	JRC 2019
Superphosphate 45%	541.97	JRC 2019
acid phosphoric	541.97	JRC 2019
Ground phosphate rock	95.00	Jenssen & Kongshaug 2003
Others		
MgO (kg MgO)	769.00	Jenssen & Kongshaug 2003
Sodium (Na) fertiliser (kg Na)	1620.00	Jenssen & Kongshaug 2003
Dolomite (CaO 30%, MgO 20%)	39.07	JRC 2019
Lime (CaO 52%)	69.73	JRC 2019
Crop treatments		
herbicides	8.985	Bochu et al. 2013
insecticides	25.134	Bochu et al. 2013
fungicides	6.009	Bochu et al. 2013
other treatments	8.478	Bochu et al. 2013

For upstream emissions of transport fuels, see Table 36.

3. Livestock production

The livestock module includes the following elements:

- CH_4 emissions from enteric fermentation
- CH_4 emissions from manure management and storage
- Direct and indirect N_2O emissions from manure management and storage
- Direct and indirect N_2O emissions from pastures

Generally, all major emission sources from ruminants (enteric fermentation and manure emissions) are based on the simplified IPCC Tier 2 methodology whereas all other emissions are based on a Tier 1 approach. The tool includes a feed module. The detailed feed intake is used to calculate emission from enteric fermentation, from manure management and from upstream emissions.

3.1 Enteric fermentation (CH_4 emissions)

3.1.1 CH_4 emissions from enteric fermentation – line G4 & G3

The overal methodology used is the IPCC simplified Tier 2 methodology based on the 2006 IPCC guidelines and the 2019 refinement. The methodology has been adapted to the farm level. For each livestock category the methane emissions are calculated per head and then summed up to the overall emissions. Different formulas are applied for different livestock categories and are detailed in the subsequent sections.

In lines G4 and G4 the farmer has to chose the type of livestock category and the type of diet for cattle. All other calculation is based on default values. Table 8 and Table 9 list the livestock categories and other default factors.

Table 8. Livestock categories and standard data for emissions from enteric fermentation (cattle)

Dairy cattle	**Average live weight (BW)**	**Methane yield (MY)**
Source	Bochu et al. 2013	IPCC 2019 Table 10.12
Dairy cows 4000 kg milk	610	21
Dairy cows 6000 kg milk	650	21
Dairy cow 8000 kg milk	700	20
Dairy cow 10000 kg milk	750	19
Calves	50	21
Growing cattle < 2 years	250	21
Growing cattle > 2 years	550	21
Mature cattle	775	21
Meat cattle		
Mature cattle	750	14
Calves	50	21
Growing cattle < 2 years	250	14
Growing cattle > 2 years	600	14

Table 9. Livestock categories and standard data for emissions from enteric fermentation (other ruminants)

	Average live weight (BW)	DE% IPCC 2019 Table 10.2	Y_m IPCC 2019 Table 10.13
Mature sheep	70	0.50 0.50	0.06
Growing sheep	35		0.06
Mature goats	65	0.50	0.07
Growing goats	35	0.50	0.07
Horses	500	0.6	23.30 (MY)

3.1.1.1 Enteric fermentation – cattle

The emission calculation uses equation 10.21A from the 2019 IPCC refinement:

EQUATION 10.21A (NEW)
METHANE EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

$$EF = DMI \bullet \left(\frac{MY}{1000}\right) \bullet 365$$

- EF: emission factor (kg CH_4/head/yr)
- DMI: dry matter intake (kg DMI / day)
- MY: Methane yield (kg CH_4 / kg DMI)

The methane yield for the different cattle categories are listed in Table 8. The calculation of the dry matter intake is explained in the following sections.

Dry matter intake (DMI) – calves

It uses equation 10.17 (2019 refinement) and is applied to all calves in the milk and meat production.

EQUATION 10.17 (UPDATED)
ESTIMATION OF DRY MATTER INTAKE FOR CALVES

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.0582 \bullet NE_{mf} - 0.00266 \bullet NE_{mf}^{\ 2} - 0.1128\right)}{0.239 \bullet NE_{mf}}\right]$$

- BW: live body weight (kg); defaults, see Table 8
- NE_{mf}: dietary net energy concentration of diet ; defaults, see see Table 10

Table 10. NE_{mf} content of typical feeds for cattle (IPCC 2019 refinement; table 10.8A)

	NE_{mf} (MJ / kg dry matter)
High grain diet (>90%)	8
High quality forage (vegetative season legumes, grass)	7
Moderate quality forage (mid-season legumes, grass)	6
Low quality forage (straw, mature grass)	4.5

Dry matter intake (DMI) – growing cattle

It uses equation 10.18 (2019 refinement) and is applied to growing cattle < 2 and > 2 years (milk and meat).

EQUATION 10.18 (UPDATED)
ESTIMATION OF DRY MATTER INTAKE FOR GROWING CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.0582 \bullet NE_{mf} - 0.00266 \bullet NE_{mf}^{\ 2} - 0.0869\right)}{0.239 \bullet NE_{mf}} \right]$$

- BW: live body weight (kg) → defaults, see Table 8
- NE_{mf}: dietary net energy concentration of diet (see previous section)

Dry matter intake (DMI) – mature cattle (milk, non lactating)

It uses equation 10.18a (2006 IPCC) and is applied to mature cattle (milk, non lactating).

EQUATION 10.18a
ESTIMATION OF DRY MATTER INTAKE FOR MATURE BEEF CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.0119 \bullet NE_{ma}^{\ 2} + 0.1938\right)}{NE_{ma}} \right]$$

- BW: live body weight (kg) → defaults, see Table 8
- NE_{ma}: dietary net energy concentration of diet
  same as NE_{mf} (see previous section)

Dry matter intake (DMI) – mature cattle (meat)

It uses equation 10.18A (2019 refinement) and is applied to mature cattle (meat).

EQUATION 10.18A (UPDATED)
ESTIMATION OF DRY MATTER INTAKE FOR STEERS AND BULLS

$$DMI = 3.83 + 0.0143 \bullet BW \bullet 0.96$$

- BW: live body weight (kg) → defaults, see Table 8

Dry matter intake (DMI) – milk cows (lactating)

It uses equation 10.18B (2019 refinement) and is applied to lactating milk cows.

EQUATION 10.18B (UPDATED)
ESTIMATION OF DRY MATTER INTAKE FOR LACTATING DAIRY COWS

$$DMI = 0.0185 \bullet BW + 0.305 \bullet FCM$$

- BW: live body weight (kg) ➔ defaults, see Table 8
- FCM: fat corrected milk (kg / day at 3.5 %)
  - (0.4324 x kg milk) + (16.216 x kg fat)
  - Milk yield per year: defaults, see Table 8
  - Fat: default (3.5 %)

3.1.1.2 Enteric fermentation – other livestock

The formula used is based on the equation 10.21 in the 2006 IPCC:

EQUATION 10.21
CH_4 EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

$$EF = \left[\frac{GE \bullet \left(\frac{Y_m}{100} \right) \bullet 365}{55.65} \right]$$

- Y_m: methane conversion factor (%)
- GE: gross energy intake of the animal; converted into DMI (GE = 18.45 X DMI)
- DMI: see below

Dry matter intake (DMI) and Y_m– sheep, goats, horses

The methan conversion factors for sheep, goats and horses are listed in Table 9. The calculation of dry matter intake is based n equation 10.17 (2006 IPCC).

EQUATION 10.17
ESTIMATION OF DRY MATTER INTAKE FOR GROWING AND FINISHING CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.2444 \bullet NE_{ma} - 0.0111 \bullet NE_{ma}^{\;2} - 0.472\right)}{NE_{ma}} \right]$$

- BW: live body weight (kg) ➔ defaults, see Table 9
- NE_{ma}: dietary net energy concentration of diet
  - NE_{ma} = REM x 18.45 X DE%
  - DE%: digestibility of feed ➔ defaults, see Table 10
  - REM: ratio net energy available in diet for maintenance to digestible energy based on equation 10.14 (2006 IPCC guideline):

EQUATION 10.14
RATIO OF NET ENERGY AVAILABLE IN A DIET FOR MAINTENANCE TO DIGESTIBLE ENERGY

$$REM = \left[1.123 - \left(4.092 \bullet 10^{-3} \bullet DE\right) + \left(1.126 \bullet 10^{-5} \bullet (DE)^2\right) - \left(\frac{25.4}{DE}\right) \right]$$

Dry matter intake (DMI) and Y_m– pigs, pultry

For pigsan poultry , both for DMI and Y_m, default values are used which are listed in Table 11.

Table 11. DMI and Y_m for pigs and poultry

	DMI Bochu et al. 2013	**Y_m** Leip 2010
Mature pigs	3.44	0.006
Growing pigs	0.91	0.006
Hens	0.10089	0.006
Broiler chicken	0.10647	0.006
Other poultry	0.10116	0.006

3.1.2 CH_4 emissions from enteric fermentation – G2

In principle, the calculation follows the same equation as in line G4 and G3 (see sections). In line G2 the farmer may use own data for the cattle:

- Live weight (kg / head)
- Lactating days
- Milk yield (kg / year)

3.1.3 CH_4 emissions from enteric fermentation – G1

Line G1 uses the same equation for emission calculation and the same defaults for the methane yield (YM or Y_m). The dry matter intake, however, is based on real feed data that have to be filled in by the farmer. For doing so, a feed module is included that covers the following feed types with their default dry matter contents:

- Forage (19 types)
- Simple feedstuff (18 types)
- Concentrate (1 type per livestock category)

The module is also used to calculate deatiled upstream emissions from feedstock purchased (see section 3.4).

3.2 Manure management (CH_4 emissions)

3.2.1 CH_4 emissions from manure management – line G4 to G3

The emission calculation uses equation 10.21A from the 2019 IPCC refinement:

EQUATION 10.23
CH_4 EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0.67\, kg/m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)}\right]$$

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days yr^{-1}

$B_{o(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted

- EF: emission factor (kg CH_4/head/yr)
- VS: daily volatile solid excreted per livestock category (kg dry matter / animal)
- B_o: maximum methane producing capacity for manure (m^3 CH_4 / kg VS excreted)
- 0.67 kg/m^3: methane density
- MCF: methane conversion factor for the manure management system (%)
- MS: Manure management system

The farmer has to choose the livestock category (same as for emissions from enteric fermentation), the share of manure that goes into the different manure management systems and the mean annual temperature (°C). For the other variables the following default values are used:

Volatile Solid excretion rates (VS)

The VS amount is based on default values, listed in Table 12.

Table 12. VS rate per livestock category

	Average live weight (BW)	Volatile solid excretion rate (kg VS/1000 kg BW/d)
Source		IPCC 2019, table 10.13A
Dairy cattle		
Dairy cows 4000 kg milk	610	8.20
Dairy cows 6000 kg milk	650	7.10
Dairy cow 8000 kg milk	700	7.10
Dairy cow 10000 kg milk	750	7.10
Calves	50	7.10
Growing cattle < 2 years	250	7.10
Growing cattle > 2 years	550	7.10
Mature cattle	775	7.10

Meat cattle		7.10
Mature cattle	750	
Calves	50	6.65
Growing cattle < 2 years	250	6.65
Growing cattle > 2 years	600	6.65
Goats		
Mature goats	70	9
Growing goats	35	9
Sheep (milk and meat)		
Mature sheep	65	8.2
Growing sheep	35	8.2
Swine		
Mature pigs	250	4.25
Growing pigs	32	5.1
Poultry		
Hens	1.95	9
Broiler chicken	2	16.1
Other poultry	1.9	12.5

Maximum methane producing capacity for manure (B_O)

The B_O is based on default values, listed in Table 13.

Table 13. B_O per livestock category

	Maximum methan producing capacity for manure B_O (m^3 CH_4 /kg VS)
Source	IPCC 2006 Table 10A-4 – 10A-10
Dairy cattle	0.24
Meat cattle	0.18
Sheep	0.19
Goats	0.18
Horses	0.3
Pigs	0.45
Poultry	0.36

MCF: methane conversion factor for the manure management system

The methane conversion factors (MCF) depend on the type of manure management and the temperature. The methodology includes 17 manure management systems. The default MCF values for each management systems, by temperature, can be consulted in the 2006 IPCC Guidelines (chapter 10 - table 10.17.).

3.2.2 CH_4 emissions from manure management – line G2 to G1

In general, the same equations and variables are used as in line G4 and G3. However, instead of using default body weights for each livestock category, the farmer can include own data on specific body weights.

3.3 Manure management (direct and indirect N_2O emissions)

Bsides the emissions from manure management (disaggregated into different manure managemet systems) this section also includes N_2O emissions from pasture (under the IPCC this is included in the soil emissions (see section 2.1)

3.3.1 Direct N_2O emissions – line G4 to G2

Direct N_2O emissions from the treatment and the storage of manure are estimated with the Tier 2 method, based on equation 10.25 in the 2019 refinement:

$N_2O = ((((N \times Nex) \times AWMS) + N) \times EF) \times 44/28$

- N_2O: emissions (kg N_2O / year)
- N: Number of livestock heads → to be filled in by farmer
- N_{ex}: N excretion per head and by animal category (kg / head / year)
- AWMS: fraction of annual nitrogen excretion managed in each manure management system (both stable and pasture) → to be filled in by farmer
- EF: emission factors for direct N_2O emissions (per management system)

Table 14. N excretion per head livestock category

	N excretion [kg / head / year]
Source	Bochu et al. 2013
Dairy cattle	
Dairy cows 4000 kg milk	107
Dairy cows 6000 kg milk	113
Dairy cow 8000 kg milk	125
Dairy cow 10000 kg milk	137
Calves	6
Growing cattle < 2 years	35
Growing cattle > 2 years	61
Mature cattle	103
Meat cattle	
Mature cattle	96
Calves	6
Growing cattle < 2 years	18
Growing cattle > 2 years	61
Goats	
Mature goats	14
Growing goats	7
Sheep (milk and meat)	
Mature sheep	14
Growing sheep	7

Swine	
Mature pigs	20.4
Growing pigs	0.62
Poultry	
Hens	0.71
Broiler chicken	0.78
Other poultry	0.72

Regarding the fraction of annual nitrogen excretion managed in each manure management system (MMS), the farmer has to fill in the percantage of the excretion that goes into the different MMS and to the pastures. The methodology includes 17 manure management systems. The default N_2O emission factor for each management systems can be consulted in the 2006 IPCC Guidelines (chapter 10 - table 10.21.).

3.3.2 Direct N_2O emissions – line G1

In general, the same equations and variables are used as in line G4 to G2. However, instead of using default N excretion rates for each livestock category, the farmer can include own data on these rates.

3.3.3 Indirect N_2O emissions – line G4 to G2

Inidrect emissions cover emissions from volatilisation and leaching / runoff:

$N2O_{indirect} = (N_{voltilization\text{-}MMS} \times EF_4 + N_{leaching\text{-}MMS} \times EF_5) \times 44/28$

- EF_4: emission factor for N_2O emissions from atmospheric deposition of nitrogen (kg N2O-N / lg N volatilised)
- EF_5: emission factor for N_2O emissions from nitrogen leaching and runoff (kg N2O-N/kg N leached and runoff)

For calculating the amount of N going into leaching and volatilisation, the 2006 IPCC Tier 1 approach is applied (equation 10.26 and 10.28):

$N_{voltilization\text{-}MMS} = (N \times N_e x \times MS) \times Frac_{GasMS})$

- $N_{volatilization\text{-}MMS}$: amount of manure nitrogen that is lost due to volatilisation of NH3 and Nox (kg N / year)
- N: number of head of livestock category
- N_{ex} = annual average N excretion per head of species (kg N / head / year)
- MS = fraction of total annual nitrogen excretion for each livestock category that is managed in manure management system (dimensionless)
- $Frac_{GasMS}$ = percent of managed manure nitrogen for livestock category that volatilises as NH3 and Nox (%)

$N_{leaching\text{-}MMS} = (N \times N_{ex} \times MS) \times Frac_{leachMS})$

- $N_{leaching\text{-}MMS}$: amount of manure nitrogen that leached from manure management systems (kg N / year)
- N: number of head of livestock category
- N_{ex}: annual average N excretion per head of species (kg N / head / year)

- MS: fraction of total annual nitrogen excretion for each livestock category that is managed in manure management system S (dimensionless)
- $Frac_{leachMS}$: percent of managed manure nitrogen losses for livestock category T due to runoff and leaching during solid and liquid storage of manure (%)

The amount of N excreted per head and livestock category is listed in Table 14.

The methodology includes 17 manure management systems. The default values for each management systems can be consulted in the 2006 IPCC Guidelines:

- $Frac_{GasMS}$: Table 10.22
- $Frac_{leachMS}$: Table 10.23

The emission factors used are IPCC 2006 Tier 1 emission factors (see Table 15)

Table 15. Emission factors for indirect N_2O emissions

EF_4 (N volatilisation and redeposition) (kg N_2O-N /kg NH_3-N + NO_x_N volatilised)	0.01
EF_5 (leaching and runoff (kg N_2O-N/kg N))	0.0075

3.3.4 Indirect N2O emissions – line G1

As for the direct N2O emissions, the farmer can fill in own N excretion rates for each livestock category.

3.4 Upstream emissions for livestock production

This section provides the indirect emissions from producing and transporting purchased feedstocks used on the farm. Energy input are summarized under section 5.

Table 16 Emission factors for feedstock upstream emissions (Bochu et al. 2013)

Fertilizer type	**Emission factor [g CO_{2equ} / kg]**
Forage	
Grazing (grasslands)	87
Grass silage	220
Maize silage	193
Hay from natural or temporary grasslands	220
Lucerne hay	220
Barn dried hay	
Beet feed	40
Green rape	60
Sorghum feed	60
Fodder kale	60
Dehydrated beet pulp	150
Squeezed beet pulp	307
Sugar beet molasses	120

By-products of beer production (squeezed)	150
Dehydrated alfalfa	150
Fresh beet pulp	500
NH3 treated straw	150
Non-treated straw	150
Pea straw	150
Single feedstocks	
Wheat	353
Barley	321
Maize for grain	296
Triticale	353
Oat	321
Sorghum seed	296
Soya seed	59
Peas seed	122
Rape seed	810
Sunflower seed	486
Soya bean meal	1579
Rapeseed cake	460
Sunflower cake	294
Flax seed	295
Milling products	541
Corn gluten feed	493
Dried beet flesh	29
Hard wheat	580
milk powder	110
Concentrates	
Concentrate cows	708
Concentrate pigs	288
Concentrate poultry	215
Concentrate goats	753
Concentrate sheep	584
Concentrate horses	475

4. Carbon storage and carbon stock changes

The calculation of carbon storage and stock changes includes the following elements:

1. Carbon stocks, i.e. carbon stored in the pools:
    a. Soil (organic, mineral)
    b. Biomass (above and below ground)
    c. Dead organic matter (DOM; dead wood, litter)
2. Carbon stock changes leading either to carbon missions or removals due to
    a. land use changes (between different land use categories)

b. management changes (within one land use category)

At farm level, carbon stocks and carbon stock changes are calculated for cropland (including fallow and agroforestry), grassland (permanent and non-permanent), woody elements (trees, hedges) and forests.

4.1 Carbon storage and carbon stock change in soils

4.1.1 Mineral soils

4.1.1.1 Carbon stock mineral soils - line G4 & G3

Cropland

The default soil carbon stock in mineral soil is calculated following equation 2.25 in IPCC 2006 (chapter 2), where a range of stock change factors are applied to a reference soil organic carbon content:

$SOC = SOC_{REF} \times F_{LU} \times F_{MG} \times F_{I}$

with

- SOC: soil content of organic carbon (mass of carbon per ha)
- SOC_{REF}: reference content of soil organic carbon in the humus layer from 0 to 30 cm (mass of carbon per ha).
- F_{LU} stock change factor for land-use systems or sub-systems for a particular land-use
- F_{MG}: stock change factor for management regime
- $FI_{:}$ stock change factor for input or organic matter

The following tables show the reference soil organic carbon content and the stock change factors applied to cropland.

Table 17. Default reference soil organic C stocks (SOCREF) for mineral soils (t C / ha in 0-30 cm depth) (Source: IPCC 2006 chapter 5, table 5.5)

Climate region	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils	Wetland soils
boreal	68		10	117	20	146
cool temperate dry	50	33	34		20	87
cool temperate moist	95	85	71	115	130	87
warm temperate dry	38	24	19		70	88
warm temperate moist	88	63	34		80	88

Table 18. Land use factors cropland (F_{LU})

Land-use	Temperature regime	Moisture regime	Land use factors (IPCC 2006, chapter 5, table 5.5.)
Annual crop	temperate boreal	dry	0.8
Annual crop	temperate boreal	moist	0.69
Tree crop	temperate boreal	dry	1
Tree crop	temperate boreal	moist	1
Vineyard	temperate boreal	dry	1
Vineyard	temperate boreal	moist	1

Table 19. Land management factors cropland (F_{MG})

Land-use management	Temperature regime	Moisture regime	Land management factors (IPCC 2006, chapter chapter 5, table 5.5.)
full tillage	temperate boreal	dry	1
full tillage	temperate boreal	moist	1
reduced tillage	temperate boreal	dry	1.02
reduced tillage	temperate boreal	moist	1.08
no tillage	temperate boreal	dry	1.1
no tillage	temperate boreal	moist	1.15

Table 20. Input level (F_I) identification

crop residues	organic amendment	green covers and residues stay on field	input level
removed	yes	yes	high man
removed	yes	no	medium
removed	no	yes	medium
removed	no	no	low
incorporated	yes	yes	high man
incorporated	yes	no	high man
incorporated	no	yes	high
incorporated	no	no	medium

Table 21. Input level (F_I)

Level	Temperature regime	Moisture regime	Input level factors (IPCC 2006, chapter 5, table 5.5.)
low	temperate boreal	dry	0.95
low	temperate boreal	moist	0.92
medium	temperate boreal	dry	1
medium	temperate boreal	moist	1
high	temperate boreal	dry	1.04
high	temperate boreal	moist	1.11
high man	temperate boreal	dry	1.37
high man	temperate boreal	moist	1.44

Grassland

Grassland is differentiated between temporary grassland / fallow and permanent grassland.

For both types, the SOC_{REF} is based on the same methodology / values as the cropland (see Table 17). The stock change factors differ and are displayed in the following tables.

Table 22. Land use factors temporary grassland / fallow (F_{LU})

Land-use	Temperature regime	Moisture regime	Land use factors (IPCC 2006, chapter 5, table 5.5.)
temporary grassland	temperate boreal	dry	0.8
temporary grassland	temperate boreal	moist	0.69
set aside	temperate boreal	dry	0.93
set aside	temperate boreal	moist	0.82
Permanent grassland	All	all	1

The land management factors (F_{MG}) for temporary grassland / fallow are the same as for cropland (see Table 19).

Table 23. Selection of land management factors permanent grassland (F_{MG})

over grazing	major long-term loss of productivity	fertilisation (mineral, organic, pasture)	grassland level
yes	yes	yes	severely degrated
yes	no	no	moderately degrated
yes	yes	no	severely degrated
yes	no	yes	moderately degrated
no	yes	yes	improved
no	no	no	nominally managed
no	no	yes	improved
no	yes	no	nominally managed

Table 24. Land management factors permanent grassland (F_{MG})

Land-use management	Temperature regime	(IPCC 2006, chapter 5, table 5.5.)
nominally managed	temperate boreal	1
moderately degrated	temperate boreal	0.95
severely degrated	temperate boreal	0.7
improved	temperate boreal	1.14

The input level factors (F_I) for temporary grassland / fallow are the same as for cropland (see Table 21).

Table 25. Input level factors permanent grassland (F_I)

Land-use management	Level	Climate regime	Land management factors (IPCC 2006, chapter 5, table 5.5.)
Improved grassland	Medium	All	1
Improved grassland	High	All	1.11

4.1.1.2 Carbon stock changes from management changes - line G4 & G3

The carbon pool in mineral soils is influenced both by land use changes (e.g. the conversion of grassland into cropland) and management changes.

Based on the current C stock, the stock changes is calculated as follows both for cropland and grassland. The difference is calculated between the current situation at the farm and the worst combination of tillage factors and input factors on this type of soil and climatic zone. The methodlogy takes into account three possible management practices:

1) Return of crop residues to the field instead of removing it
2) Application of organic fertiliser (e.g. manure, sewage sludge, digestate)
3) Implementation of green covers

4.1.1.3 Carbon stock mineral soils - line G2 & G1

The current carbon stock is inputted by the farmer and is transferred from the nutrient module.

4.1.1.4 Carbon stock changes from managemet changes - line G2 & G1

The following options for management changes are included:

- Change of tillage
- Implementation of cover cropping
- Implementation of compost
- Implementation of manure additions
- Incorporation of residues

The type and time duration of each of the management changes are asked for. Hereby, the change can work in both directions: either the change towards a more carbon storing type or vice versa. For each change, an annual increase or deacrese of the actuacl SOC is calculated based on the following formula:

$CO2\text{-}C_{sequestration} = -1 \times (F_{change}-1) \times SOC \times A$

$CO2\text{-}C_{change}$: CO2 sequestration or emission due to management changes (

Fchange: overall factor reflecting the changes in SOC due to management changes

SOC: soil organic carbon content → transferred from nutrient module or filled in by farmer

A: area where the management change is applied

The overal management change factor is the sum of the factors from singlea measures:

$F_{change} = F_{till} + F_{cover} + F_{com} + F_{man} + F_{res}$

- F_{till}: change factor from tillage changes
- F_{cover}: change factor due to cover crop changes
- F_{com}: change factor due to compost management changes
- F_{man}: change factor due to manure management changes
- F_{res}: change factor due to residue management changes

The change factors for tillage and cover crops are listed in Table 26.

For residues, compost and manure, a different approach is applied. The amount of N applied with the manure, residues or compost (N) has to be filled in by the farmer. If a management change has started, the followng formula is applied:

$F_{com\text{-}start}, F_{man\text{-}start}, F_{res\text{-}start} = 1+(N \times F_{com}, F_{man}, F_{com} /1000)$

If the change stops, the following formula is applied:

$F_{com\text{-}stopp}, F_{man\text{-}stopp}, F_{res\text{-}stopp} = 1/(1+(N * F_{com}, F_{man}, F_{com} /1000))$

The factors applied are also listed in Table 26.

For example, if a farmer changed from conventional tillage to no tillage 5 years ago and if the SOC is 4500 kg / ha, the calculation is a follows:

$CO2\text{-}C_{sequestration}$ = -1 x (1.008-1) X 45000 X 1 = -36 kg C / ha / year

Table 26. Change factors for SOC from management changes

Management change		**temperate moist kg C / ha / year**	**temperate dry**	**Source and comments**
Tillage	no change	1	1	
	conventional to reduced	1.0045	1.0015	Calculated based on Ogle et al. 2005
	conventional to no-till	1.0080	1.0050	Calculated based on Ogle et al. 2005
	reduced to conventional	0.9959	0.9985	Calculated based on Ogle et al. 2005
	reduced to no till	1.0032	1.0034	Calculated based on Ogle et al. 2005
	no till to reduced	0.9970	0.9968	Calculated based on Ogle et al. 2005
	no till to conventional	0.9931	0.9955	Calculated based on Ogle et al. 2005
Cover cropping	no change	1	1	
	started adding	1.0049	1.0043	Calculated based on Ogle et al. 2005
	stopped adding	0.9955	0.9960	Calculated based on Ogle et al. 2005
compost	no change	0	0	
	Management change	0.0008	0.0008	Smith et al. 1997
manure additions	no change	0	0	
	Management change	0.00036	0.00036	Smith et al. 1997
Residues	no change	0	0	
	Management change	0.00124	0.00124	Smith et al. 1997

4.1.2 Cultivated organic soils – lines G4 to G1

As described in chapter 2.3, the drainage and cultivation of organic soils leads to big N_2O, Ch_4 and CO_2 emissions. In the Navigator, the rewetting of oranic soils can be chosen as a management change option. Soil rewetting may lead to lower emissions (CO_2, N_2O) but, on the other hand, causes high CH_4 emissions.

If a formerly drained soil is marked as rewetted, the emissions are calculated based on the emission factors in Table 27. For comparison, the emission factors before rewetting are displayed as well (see section 2.3.

Table 27. Annual emission factors for rewetted organic soils (sources: IPCC 2013 wetland supplement (table 3.1, 3.2, 3.3))

Climatic temperature regime	**EF CO_2 (t C ha-1yr-1)**	**EF DOC (t C / ha)**	**EF CH_4 (kg CH4 / ha)**	**N_2O (kg N_2O-N / ha)**
temperate	0.135	0.26	154	0
boreal	-0.445	0.08	89	0
Before rewetting	5.18 -7.9	0.12 – 0.31	0 – 14.1	5.9 - 13

4.2 Carbon storage and carbon stock change in biomass

Carbon can be stored in cropland, natural elements (e.g. hedges, single trees) and forests. In cropland, the storage is calculated only in perennial woody crops and agroforestry systems. In annual crops it is assumed that the increase in biomass stocks in a single year is equal to biomass losses from harvests in that same year. As a result, there is no net accumulation of biomass carbon stock.

4.2.1 Perennial crops & natural elements

Perennial crops and natural elements include the following crops / systems: fruit orchards, plantation crops, agroforestry systems, single woody elements (e.g. trees, hedges).

Natural elements are categorised as follows:

1. Single trees (< 5 m high)
2. Shrubs (1 – 5 m high)
3. Vineyards / orchards
4. Low natural elements (< 1m high)

The carbon stock is only calculated for above ground biomass. In the Tier 1 approach it is assumed that there is no change in below-ground biomass in perennial crops and natural elements. Also dead organic matter (DOM) is not taken into account since it is assumed that they are at equilibrium (thus there is not net carbon stock change).

4.2.1.1 Perennial crops and natural elements – lines G4 to G2

In lines G4 to G2, the methodology of carbon stocks and carbon stock changes follow the IPCC 2006 Tier 1 approach. The **carbon stock** corresponds to the surface of the natural elements:

width [m] x length [m] = surface [m²]

multiplied with the carbon stock [t C / ha].

Table 28 to Table 30 display the default carbon storages per category.

Table 28. Carbon storage in tree natural elements (>5 m high) (Bochu et al. 2013)

Tree natural elements (> 5 m high)	Characteristics	Current C storage [t C / ha]
Grove < 0,5 ha		120
Maintained hedgerow 3 stratum	More than 3 trees for 25 m linear	120
Damaged hedgerow (basis <1,5 m)		100
Tree line	Road side. Standard width = 5 m	100
Scattered tree (adult)	100 m2/ tree	100
Riverine	Along the stream	120
Wood edges	Wood> 0,5ha, take 10m width and count the wood edges lenght	0

Table 29. Carbon storage in shrubby natural elements (1-5 m high) (Bochu et al. 2013)

Shrubby natural element (1 to 5 m high)	Characteristics	Current C storage [t C / ha]
Shrubby hedgerow	Less than 3 trees for 25ml	94
Bank with shrub		94
Wildland, heath	Less than 3 trees for 0,5 ha	94
Vineyards		94
Orchards		94

Table 30. Carbon storage in shrubby natural elements (1-5 m high) (Bochu et al. 2013)

Low natural elements (< 1 m high)	Characteristics	Current C storage (soil + wood) [tC / ha]
Grass strips		50
Green cover bank		70
Dry lawn	Non used by agriculture	70
Wet natural meadow	Non used by agriculture	90
Young hedgerow (0-3 years)	Hedgerow recenlty planted	50
Young hedgerow (4-7 years)		59
Stone low wall		0
Ponds < 1000 m^2		0

The **carbon stock change** is calculated as an annual increase in C stock. An increase in C storage of 0.1 t C / ha / yr has been assumed (Bochu et al. 2013).

4.2.1.2 Perennial crops and natural elements – line G1

In line G1 the farmer can use own data both on the current carbon stock as well as on the carbon stock change / growth rate.

4.2.2 Forests

Generally, the calculatcion of carbon stocks and stock changes are based on euqation 2.7 in the 2006 IPCC guidelines (chapter 2) where the annual change in carbon stock is the sum of the anucal increase due to biomass growth and the dreacreas due to losses from harvets and disturbances (e.g. pests, fire).

4.2.2.1 Carbon storage and carbon stock change – lines G4 to G2

Lines G4 to G 2 are mainly based on default values published in the 2019 IPCC refinements. The calculation of the annual gain in biomass is based on equation 2.9. The default factors used are listed in Table 31.

Table 31. Carbon storage in forests (tables 4.7, 4.9, 4.4, 4.3 in 2019 IPCC refinement)

Forest Climate zone	**Current C storage (above ground biomass) [t dm / ha]**	**Above ground net biomass growth [tdm/ha/yr]**	**Ratio below ground biomass to above ground biomass**	**Carbon fraction above ground biomass [t C / t dm]**
Temperate oceanic <20y coniferous	120	2.3	0.29	0.51
Temperate oceanic >20y coniferous	120	2.3	0.29	0.51
Temperate oceanic <20y broadleaf	120	2.3	0.23	0.48
Temperate oceanic >20y broadleaf	120	2.3	0.23	0.48
Temperate continental <20y coniferous	20	4	0.4	0.51
Temperate continental <20y broadleaf	20	4	0.46	0.48
Temperate continental >20y coniferous	120	4	0.29	0.51
Temperate continental >20y broadleaf	120	4	0.23	0.48
Temperate mountain system <20y coniferous	100	3	0.29	0.51

Temperate mountain system <20y broadleaf	100	3	0.23	0.48
Temperate mountain system <20y coniferous	130	3	0.29	0.51
Temperate mountain system <20y broadleaf	130	3	0.23	0.48
Boreal <20y coniferous	50	1.1	0.39	0.51
Boreal >20y coniferous	50	1.1	0.39	0.51
Boreal <20y broadleaf	50	1.1	0.39	0.48
Boreal >20y broadleaf	50	1.1	0.39	0.48
Boreal tundra <20y coniferous	3.5	0.4	0.39	0.51
Boreal tundra <20y broadleaf	3.5	0.4	0.39	0.48
Boreal tundra >20y coniferous	17.5	0.4	0.39	0.51
Boreal tundra >20y broadleaf	17.5	0.4	0.39	0.48
Boreal mountain <20y coniferous	13.5	1.05	0.39	0.51
Boreal mountain <20y broadleaf	13.5	1.05	0.39	0.48
Boreal mountain >20y coniferous	45	1.3	0.39	0.51
Boreal mountain >20y broadleaf	45	1.3	0.39	0.48

The losses from harvest are based on equ. 2.12 (2006 IPCC guideline, chapter 2):

H x BCEFR x (1+BF+R) x CF

with

- H: merchantable wood over bark [m³] ➔ to be included by farmer
- BCEFR: biomass conversion and expansion factor ➔ see Table 32
- BR: bark fraction in harvested wood ➔ to be included by the farmer
- R: ratio of below-ground biomass to above-ground biomass ➔ see Table 31
- CF: carbon fraction of dry matter ➔ see Table 31

Table 32. Biomass conversion and expansion factors (BCEFR) (table 4.5 in 2019 IPCC refinement)

Forest Climate zone	**Biomass conversion and expansion factors (BCEFR)**
Temperate broadleaf <20	3.33
Temperate broadleaf 21-40	1.89
Temperate broadleaf 41-100	1.55
Temperate broadleaf 101-200	1.17
Temperate broadleaf > 200	0.89
Temperate coniferous <20	2.67
Temperate coniferous 21-40	1.33
Temperate coniferous 41-100	0.97
Temperate coniferous 101-200	0.8
Temperate coniferous > 200	0.77
Boreal coniferous <20	1.32
Boreal coniferous 21-50	0.78
Boreal coniferous 51-100	0.71
Boreal coniferous >100	0.66
Boreal braodleaf <20	1
Boreal broadleaf 21-50	0.77
Boreal broadleaf 51-100	0.69
Boreal boradleaf >100	0.61

Loss from disturbances is based on equ. 2.14 (2006 IPCC guideline, chapter 2):

$A_{disturbance}$ x B_W x (1+ R) x CF x fd

- $A_{disturbance}$: Area of disturbance [ha] ➔ to be included by farmer
- B_W: average above-ground biomass affected (above ground net biomass growth) ➔ Table 31
- R: ratio of below-ground biomass to above-ground biomass ➔ see Table 31
- CF: carbon fraction of dry matter ➔ see Table 31
- fd: fraction of biomass lost in disturbance [%] ➔ to be filled in by farmer

4.2.2.2 Carbon storage and carbon stock change – line G1

Line G1 follows the same logic as the other lines, i.e. the annual change in carbon stock is the sum of the annual increase due to biomass growth and the dreacreas due to losses from harvets and disturbances.

However, insteand of using default data, the farmer can use own data both on the current carbon stock as well as on the growing stock volume.

4.3 Carbon stock canges from land use changes

The Navigator takes into account land use changes that ocurred over the past 20 years. The following conversion types are included:

- Conversion of forest to cropland
- Conversion of forest to grassland
- Conversion of grassland to cropland
- Conversion of cropland to grassland
- Conversion of cropland to forest

For the changes in carbon stock, the following default values are used.

Table 33. GHG emissions from land use change (Bochu et al. 2013)

Conversion type	GHG emissions for LUC (t CO_2/ha/year, 20 yrs average)
Conversion of forest to cropland	5
Conversion of forest to grassland	0
Conversion of grassland to cropland	5
Conversion of cropland to grassland	-5
Conversion of cropland to forest	-5
Conversion of grassland to forest	0

5. Energy use

The Navigator asks for the annual amount of energy used, namely electricity, energy carriers for heat production and fuels (for transportation and field work). The amount of energy / energy carriers refers to the farm as whole and is not differentiated between the different parts. One xemption is the amount of fuel used for field work which is covered in the crop module (see section 2.4).

Upstream missions are applied only to energy / energy carriers that are purchased. Those produced on farm (e.g. biogas, biofuels) are set to zero emissions.

Table 34. Emission factors for electricity consumed

Electricity mix	g CO2eq / MJ	Source
Electricity EU average mix (≥110 kV)	135.99	JRC 2019
Electricity EU average mix (10-20 kV)	141.13	JRC 2019
Electricity EU average mix (0.4 kV)	150.11	JRC 2019
Electricity EU fossil mix (≥110 kV)	185.91	JRC 2019
Electricity EU fossil mix (10-20 kV)	192.93	JRC 2019
Electricity EU fossil mix (0.4 kV)	205.21	JRC 2019
Austria	52.14	BioGrace II additional standard values
Belgium	59.41	BioGrace II additional standard values
Bulgaria	191.55	BioGrace II additional standard values
Croatia	112.21	BioGrace II additional standard values
Cyprus	263.15	BioGrace II additional standard values

Czech Republic	196.99	BioGrace II additional standard values
Denmark	115.67	BioGrace II additional standard values
Estonia	321.06	BioGrace II additional standard values
Finland	63.53	BioGrace II additional standard values
France	22.66	BioGrace II additional standard values
Germany	169.90	BioGrace II additional standard values
Greece	242.99	BioGrace II additional standard values
Hungary	120.05	BioGrace II additional standard values
Ireland	164.22	BioGrace II additional standard values
Italy	137.82	BioGrace II additional standard values
Latvia	60.87	BioGrace II additional standard values
Lithuania	127.09	BioGrace II additional standard values
Luxemburg	82.38	BioGrace II additional standard values
Malta	356.17	BioGrace II additional standard values
the Netherlands	146.36	BioGrace II additional standard values
Poland	285.94	BioGrace II additional standard values
Portugal	137.12	BioGrace II additional standard values
Romania	176.35	BioGrace II additional standard values
Slovakia	69.41	BioGrace II additional standard values
Slovenia	122.14	BioGrace II additional standard values
Spain	106.81	BioGrace II additional standard values
Sweden	6.11	BioGrace II additional standard values
United Kingdom	164.80	BioGrace II additional standard values

Table 35. Emission factors for fossil energy carriers (JRC 2019)

Energy carriers	**Emission factor [g CO_{2eq}/MJ]**
Fuel oil	94.20
Heavy fuel oil	94.20
Hard coal	112.32
Lignite	116.73
Natural gas (EU-mix)	66.00
LPG	66.31

Table 36. Emission factors for transport fuels

Transport fuels	**Emission factor [kg CO_{2eq}/liter]**	**Source**
Fuel oil	3.70	JRC 2019
Diesel	3.41	JRC 2019
Gasoline	3.00	JRC 2019
Rape seed biodiesel	1.06	RED II default value
Sunflower biodiesel	0.86	RED II default value
Biodiesel mix	0.87	RED II default value
PVO rapeseed	1.14	RED II default value
PVO sunflower	0.93	RED II default value
PVO mix	0.94	RED II default value

6. References

Bochu, J.L., Metayer, N., Bordet, C.; Gimaret, M. (2013): Development of Carbon Calculator to promote low carbon farming practices – Methodological guidelines (methods and formula), Deliverable to EC-JRC-IES by Solagro

Bouwman et al. (2002): Bouwman, A.F., Boumans, L.J.M. and Batjes, N.H. (2002): Emission of N_2O and NO from fertilized fields : Summary of available measurement data. Glob. Biogeochem. Cycles, 16 (4), art. No. 1058.

Brentrup, F. & Pallière, C. (2014): Energy efficiency and GHG emissions in European nitrogen fertiliser production and use.

Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. (S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.). IGES, Japan. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

IPCC (2013). 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds)). Retrieved from https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/

IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Prepared by the prepared by the Task Force on National Greenhouse Gas Inventories (TFI) (S. M. Ogle, M. J. Sanz Sanchez, M. T. Rocha, J. D. MacDonald, H. Dong). Retrieved from https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

Jenssen, T.K. & Kongshaug G. (2003): Energy Consumption and Greenhouse Gas Emissions in Fertiliser Production, Proceedings No. 509. International Fertiliser Society York, UK.

JRC 2014: Joint Research Center (JRC) 2014: The Global Nitrous Oxide Calculator – GNOC – Online Tool Manual. Retrieved from https://gnoc.jrc.ec.europa.eu/

JRC 2019: Edwards, R., O'Connell, A., Padella, M., Giuntoli, J., Koeble, R., Bulgheroni, C., Marelli, L., Lonza, L. (2019): Definition of input data to assess GHG default emissions from biofuels in EU legislation.

Leip, A. (2010): Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) – JRC

Ogle, S.; Breidt, F.; Paustian, K. (2005): Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions; in: Biochemistry, vol 72, pp 87-121

Smeets et al. (2009): Smeets, E. M. W., Bouwman, L. F., Stehfest, E., Van Vuuren, D. P., & Posthuma, A. (2009): The contribution of N_2O to the greenhouse gas balance of first-generation biofuels. Global Change Biology, 16(8), 2400–2400. doi:10.1111/j.1365-2486.2010.02271.x

Smith, P., Smith, J.U., Powlson, D.S., McGill, W.B., Arah, J.R.M., Chertov, O.G. et al. (1997): A comparison of the performance of nine soil organic matter models using datasets from seven longterm experiments. Geoderma, 81, 153–225.

Stehfest, E. & Bouwman, L. (2006) N2O and NO emission from agricultural fields and soils under natural vegetation: Summarizing available measurement data and modeling of global annual emissions. Nutr. Cycl. Agroecosystems 74, 207–228.