



# Description of the Agrosfär model

*– a tool for climate impact assessment of crop and animal production systems in Sweden*

Version 1: Crops, milk and beef

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# Foreword

Agrosfär is an EIP-Agri financed project aiming to develop a software solution that can calculate climate footprint on a detailed level within the primary food production in Swedish Agriculture. This report describes the first version of the climate calculation model used in the software solution (product component 3 in the project description). The other components of the project are (1) automate retrieval of data from existing data sources, (2) establish a framework and common data protocol so that data can be harmonised in between data sources, (4) develop AI capabilities for decision support in climate improvements measures on farm level, and (5) visualise climate footprint over time and the effects of improvement measures to support integrated climate work in the food chain.

The calculation model team has consisted of specialists from Lantmännen, Hushållningssällskapet, and RISE with support from a project manager and a data scientist who has worked with the first version of the model between November 2021 and April 2022. The model will be implemented in the Agrosfär software and tested by farmers mid-2022 and developed and deployed to more users over time.

Agrosfär is a product of Agronod; owned by Växa, Lantmännen, LRF and Hushållningssällskapet.

# Summary

The agricultural sector in Sweden needs to cut GHG emissions and contribute to the climate goal of net-zero emissions by 2045. The GHG reduction goal for agricultural emissions is not quantified, but the Swedish climate policy framework states that *‘the Swedish food production shall increase as much as possible with as little climate impact as possible’* and multiple key actors within the sector of food and agriculture have developed roadmaps or industry specific goals for reducing GHG emissions from the sector. Consequently, requirements of transparent GHG accounting and reporting are increasing within the agricultural sector, both at national and international level.

The purpose of the Agrosfär tool is to establish an automatic data driven climate calculator used to calculate GHG emissions from agricultural products and on farm enterprise level. The automation and automatic data collection will save time, increase accuracy of the calculations, and simplify updates of the tool to keep it aligned with the most recent climate data and climate reporting methodology. It will make it possible to continuously carry out follow-ups on climate performance indicators and measure improvements from climate measures taken.

A working group consisting of Swedish agricultural life cycle assessment experts have developed the framework of the tool, e.g. setting system boundaries, selecting methodologies and input data. A technical team has developed algorithms, a digital interface and coupled the tool to other existing agricultural databases providing farm specific information on crop and animal production data, soil characteristics, carbon footprints and amounts of purchased inputs etc. The tool and user interface have been developed based on input from farmers through prototyping and in-depth interviews.

For general guidelines on methodology the calculation model follows the Product Environmental Footprint Category Rules (PEFCR), the International Dairy Federation (IDF)’s approach for carbon footprint for the dairy sector and FAO Livestock Environmental Assessment and Performance guidelines (FAO LEAP). Where standards have diverged or where assumptions have been required the working group has made expert judgements on which method/guideline to follow or what assumptions to make.

A first version of the tool, a so called minimal viable product (MVP) has been developed which will be the basis for further development. The MVP contains an animal and crop module and can calculate the carbon footprint of crops, milk and beef. Future development possibilities of the tool and calculation model is described in chapter 7, such as enabling climate calculations on enterprise level, develop modules for more animal production types, deepen the integration between the crop and animal modules, expand sources for automatic data collection, develop a carbon sequestration module and other technical and methodological improvements to ensure alignment with important climate reporting standards. The report will be repeatedly updated as the tool develops, and new versions of the tool are released.

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# 1 Introduction

In a globally warmer climate, agriculture must take its share in reducing greenhouse gas emissions. In order to do so, adequate climate calculation tools are needed, to highlight hotspots in the production systems. Agricultural climate calculation tools in Sweden already exist; however these are based on manual input of data.

The goal with Agrosfär is to establish a full suit automatic climate calculator that can be used in Swedish agriculture. This will lay the foundation for efficient, data-driven farm level climate work as well as providing the food industry with updated climate data. The system will automatically collect data and structure it in a predefined framework. With a climate algorithm the data can be turned into comparable climate key performance indicators and figures which can be used as a foundation for continuous improvements, in sustainability reporting and as underlying facts in consumer communication. The result will be visualised in a digital interface that farmers and farmer partners can leverage to gain a deeper understanding of the farm footprint, the effect of different emission factors as well as provide a foundation for decision making.

To begin with, a first version of Agrosfär is being developed, a so called minimal viable product (MVP). The aim of the MVP is to test the model and its functionality and be the basis for further development. The MVP has the following features:

- It covers the climate impact of crop, milk and beef production.
- It focuses on climate calculations on a product level. Climate impact on farm level per year, will be covered in a coming version of Agrosfär.

In the construction of the model, several methodological choices must be made. The project group has discussed the methods and assumptions in regular meetings throughout the project. Support in decisions have also come from reviewing standards and guidelines for life cycle assessments (LCA), as well as scientific literature. As this is a first version of a very comprehensive model, not all sources of emissions and not all the most detailed methods have been incorporated. Areas for further development are described in chapter 7.

## 2 Methods

### 2.1 General description of model

The Agrosfär model builds on two sub models, a crop production model, and an animal production model (Figure 1).

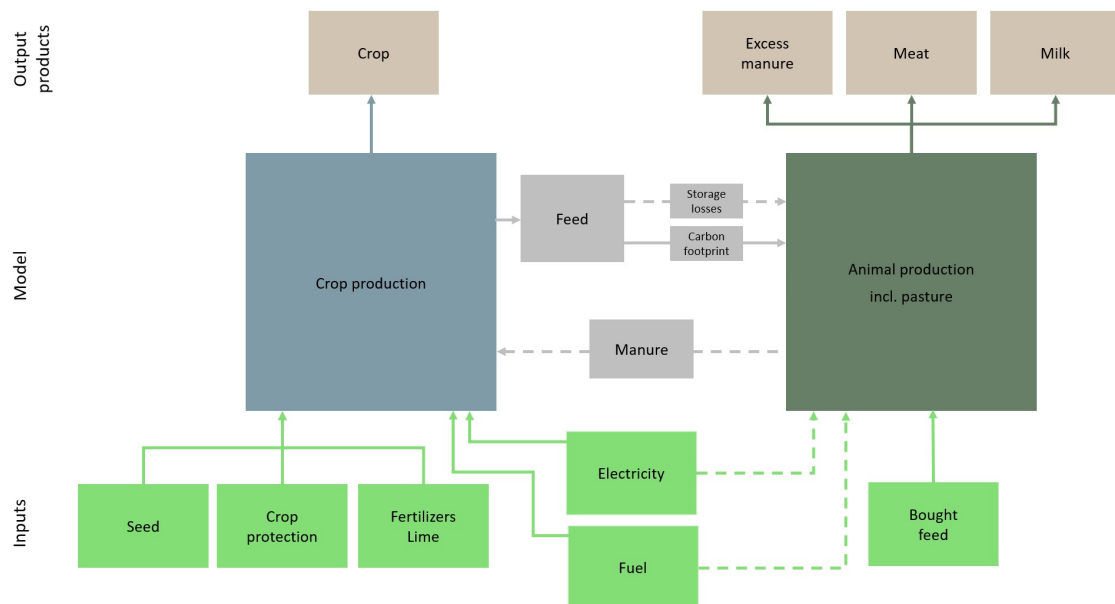


Figure 1. Schematic description of the Agrosfär model version 1, showing inputs and outputs of the model and flows between the crop and animal production. The flows represented by the dotted lines will not be implemented in the first version of Agrosfär.

**The two models are connected**, but in the MVP the connection is only via the feed grown on-farm: the calculated carbon footprints of grains and roughage in the crop model are transferred to the animal model (grey box in fig 1). However, the volume of feed (including losses) is determined by the energy need of the animals, calculated in the animal production sub-model. In the following development of the Agrosfär model, further connection will be made e.g. manure, fuel and electricity. See further description in chapter 7.

**Some processes belong** clearly to one sub model. For example, seed belong to crop production and methane from enteric fermentation belong to the animal production model. However, there are other processes that needs to be defined. In Agrosfär, the drying of cereals is part of the crop production model. Pasture and related emissions are part of animal production. Manure is part of animal production up to storage, while loading and spreading is part of crop production. Fuel (diesel, biofuels) and electricity is used in both crop and animal production. In the future development of Agrosfär, the

farmer will be able to fill in total bought fuel and electricity, and the model will then subtract the energy use in crop production (registered by automatic data collection in farm machinery) and allocate the remaining part to animal production.

**The time aspect** in modelling is of course relevant; feed is grown before it is fed to the animals. The crop for feeding the animals a certain year have often been harvested in the previous year but sometimes several years before. Likewise, manure is produced one year and spread the next year. In this first version of the Agrosfär model, we have a product focus. This means that we calculate the climate impact of producing a certain amount of crops or a certain amount of milk and meat. In this case, it is less important what year the feed is produced; the emissions from feed production will be included in the meat carbon footprint. In the future the Agrosfär model will be expanded, so that it can calculate the climate impact from a farm during one (calendar or other) year. In this case, the emissions from crop production and animal production will need to be much more carefully considered taking also into account the storage of feed over years.

**Resulting GHG emissions calculated in the model** can be extracted in several formats: for crop production, per hectare, per kg dry matter crop, per kg crop with defined moisture content, for animal production per kg ECM milk and per kg carcass weight of beef.

## 2.2 General description of calculation procedure

In general emissions are accounted as **activity \* emission factor**. For certain processes, this is done in several steps, for example the methane emissions from manure storage builds on several parameters such as the excretion rate and the methane conversion factor. Emission factors can also be based on previous LCAs, for example the model contains emission factors for purchased feed, here the activity data can be x kg of feed, and the emission factor y kg CO<sub>2</sub>-eq. per kg feed.

The general idea with the Agrosfär model is that activity data are collected automatically from databases, that the farmers choose to connect to the Agrosfär calculation tool. The following datasets and databases can be connected initially:

- Dataväxt – Provider of digital systems for crop production
- Kokontrollen – Journal system and data on cattle provided by the advisory service company Växa
- Markkartering – Field mapping service provided by the advisory service company Hushållningssällskapet
- LM2 – product information from orderings of e.g. feed from Lantmännen

Data from these sources are automatically collected and used to calculate emissions, however they are validated both by manual inspection by the farmer and long term by automatic procedures designed to catch erroneous data.

It is not always the case that the farmer is using these databases. Additionally, not all data required by the climate calculations are available from these databases. In those



cases, activity data can be manually entered to Agrosfär. Further, non-activity data such as information on manure management systems is also collected manually in most cases.

When data is manually entered to Agrosfär, there are cases where the farmer may not know all the details required. An example would be if the farmer does not know the crude fat content of a feed concentrate used. In these cases, it is possible to fill in blanks with standard values, either by replacing the incomplete product with a generic non-branded version, or by making inferences from other product parameters.

After the data is collected, emissions are calculated. In general, all relevant and available historical data is used when applicable, regardless of the period for which emissions are calculated. This ensures that no important data is missed. For instance, if a cow became pregnant during the preceding period, or if a liming agent were used several years ago, the resulting emissions are then displayed and stored, grouped by emission source and product.

## 2.3 Emission sources covered in the model

The main greenhouse gas emissions covered in the Agrosfär model are summarised in Table 1 below. Emissions of the main agricultural greenhouse gases are included: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O).

Table 1. Summary of main emissions included in the Agrosfär tool.

	Emission source	Description	GHG
Crop production	Production of inputs	Production of fertilisers, seed, pesticides, lime, fuel and other inputs used in crop production	CO <sub>2</sub> , N <sub>2</sub> O
	Use of fertilisers	Direct and indirect emissions from soil after application	N <sub>2</sub> O
	Use of manure and other organic fertilisers	Direct and indirect emissions from soil application	N <sub>2</sub> O
	Crop residues	Direct and indirect emissions from nitrogen turnover in soil, from above and below ground crop residues left in field, including straw	N <sub>2</sub> O

	Emission source	Description	GHG
	Organic soils	Emissions from organic matter oxidation when cultivating organic soils	CO <sub>2</sub> , N <sub>2</sub> O
	Cover crops and green manure	Direct and indirect emissions from nitrogen turn over in soil after green manure or cover crop	N <sub>2</sub> O
	Liming	Emissions from application lime	CO <sub>2</sub>
Animal production	Feed production	Emissions from production of purchased feed	CO <sub>2</sub>
	Enteric fermentation	Emissions from enteric fermentation in ruminants	CH <sub>4</sub>
	Manure management	Emissions from housing and storage of manure	CH <sub>4</sub> , N <sub>2</sub> O
	Other inputs	Acids for silage	CO <sub>2</sub>
Energy	Fuel use	Field operations, total on farm fuel use	CO <sub>2</sub>
	Electricity use	Grain drying, heating, on farm processes (milking, irrigation and others)	CO <sub>2</sub>
	Heat use	Grain drying, heating of stables	CO <sub>2</sub>

## 2.4 Standards and guidelines

In the development of the Agrosfär model, we have consulted several Life Cycle Assessment (LCA) standards to guide methodological choices. It was not possible to fully follow one standard, as the standards have different focus. In other words, the standards complement each other. In some cases, the standards are contradictory; in these cases, we have discussed in the project group to reach consensus. Furthermore, in some cases there are Swedish guidelines which are not developed for the purpose of LCA:s, e.g. the Swedish NIR (national inventory report which is the climate reporting to the Kyoto protocol) (Naturvårdsverket, 2021a, 2021b), but which are sometimes referred to and recommended to follow by LCA standards. In the Agrosfär tool, prioritised standards are PEFCR and FAO LEAP.

The Product Environmental Footprint (PEF) is an LCA based method to quantify environmental impacts of products on initiative by the European commission. It builds on existing approaches and international standards such as the ISO 14040-series (International organization for standardization, ISO, 2018). PEF has also developed category specific rules, PEFCR (European Commission, 2018). The PEFCR is an attempt to converge already existing standards in to one standard for various product categories. The PEFCRs are being incorporated and indicative for businesses and actors within the EU, declaring product environmental footprints, making these guidelines important for the Agrosfär tool.

FAO LEAP (Livestock Environmental Assessment Performance) is an initiative within Food and Agriculture Organisation of the UN (FAO), providing internationally harmonised guidance and methodology for assessing the environmental performance of livestock supply chains (Food and Agriculture Organization of the United Nations (FAO), 2016). FAO LEAP provides several guidelines and in the Agrosfär tool two guidelines have been of certain importance: Environmental performance of animal feeds supply chains and Environmental performance of large ruminant supply chains. The FAO LEAP guidelines follow the structure of ISO 14040:2006 on the four life cycle stages of LCA. They give guidance on data inventory, system boundaries, time boundaries for data and allocation procedures. PEF frequently refers to the FAO LEAP guidelines.

Several other important guidelines/databases follow the FAO LEAP and EU-PEF guidelines, for example GFLI (Global metrics for sustainable feed) (Global Metrics for Sustainable Feed (GFLI), 2020) and RKFS (the Swedish rules for calculating the carbon footprint of feed and grains (Foder och Spannmål, 2020)).

Many of the guidelines lean on IPCC methods for estimating emissions for each greenhouse gas from different processes. IPCC does not provide guidance on how to calculate product environmental footprints, rather it gives guidance on how to calculate certain emissions such as N<sub>2</sub>O emissions from soil (Gavrilova et al., 2019), or methane emissions from enteric fermentation (Hergoualc'h et al., 2019). The IPCC methods are divided into three different Tiers. Each tier represents a level of methodological complexity:

- Tier 1 = The basic method, simple methods based on default factors
- Tier 2 = Intermediate level, where country specific or local values should be used to obtain country specific values.
- Tier 3 = Nationally adopted model.

Decision trees are provided by the IPCC to support the decision of what Tier level is appropriate to use, and different levels can be mixed within the same report. In the Swedish national inventory reports to UNFCCC, tier 1 is used for enteric fermentation for sheep whereas tier 3 is used for enteric fermentation for dairy cows. Different guidelines usually recommend specific tiers or minimum tiers for calculating emissions from different processes (Table 2 and Table 3).

Table 2. Most important method choices in crop model.

Process	GHG	Method in Agrosfär	Guideline recommendation
Output	N/A	kg dry mass/ha and kg wet weight/ha. Mass of co-products (straw) is calculated	According to PEFCR Feed: following outputs per ha shall be provided: Main crop product and Co-product(s) (mass, DM, financial value, gross energy content), Residual materials that remain on the field or in soil (mass, DM)
Time boundary for data	N/A	Data for one cropping year will be used initially but in future as data is collected for more years, assessment periods of 3 years will be enabled.	PEFCR: For annual crops, an assessment period of at least three years shall be used (to level out differences)
Direct nitrous oxide (N <sub>2</sub> O) to air	N <sub>2</sub> O	IPCC 2019 Tier 1, table 11.1 aggregated emission factors. 1% of N applied to soil (kg N <sub>2</sub> O-N/kg N)	PEFCR (2018). Recommendation to use IPCC 2006 Tier 1 (De Klein et al., 2006) or better data
Indirect N <sub>2</sub> O due to N volatilisation	N <sub>2</sub> O	IPCC 2019 Tier 2, table 11.3. For manure application N volatilisation specific Swedish EFs are applied based on Karlsson & Rhode (2002). The EFs consider timing, spreading technique and how fast manure is incorporated into soil after spreading.	PEFCR (2018). PEFCR recommends using IPCC 2006 Tier 1 or better data
Indirect N <sub>2</sub> O due to N leaching	N <sub>2</sub> O	IPCC 2019 Tier 2, table 11.3. 1,1 % of N <sub>2</sub> O-N of leached N. Leaching of N is calculated according to Swedish model, based on data and models developed by Aronsson & Torstensson (2004).	PEFCR (2018). PEFCR recommends using IPCC 2006 Tier 1 or better data
Nitrogen content crop residues	N <sub>2</sub> O	IPCC 2019 Tier 1, table 11.1A. Level of crop residue removal is either calculated as a Yes/No question. Yes = 50% of crop residues are considered removed. No = 0% crop residues are considered removed. Or be stated as a field specific figure if known.	PEFCR (2018). N input from crop residues that stay on the field. Kg/ha and N content.
Direct N <sub>2</sub> O emissions from organic soils	N <sub>2</sub> O	IPCC 2013 Wetlands supplement. For grassland IPCC 2013 emission factors for forestland are applied as	Compliant with PEFCR dairy. PEFCR (2018) doesn't mention N <sub>2</sub> O emissions for peat soils.

Process	GHG	Method in Agrosfär	Guideline recommendation
		Swedish grasslands are more like forestland than grasslands in Europe.	
Peat oxidation	CO <sub>2</sub>	IPCC Tier 1 reworked by Lindgren and Lundblad (2014)	Compliant with PEFCE dairy.
Carbon in urea	CO <sub>2</sub>	IPCC 2019 Tier 1. Ch 11.4. 0,73 kg CO <sub>2</sub> /kg urea	PEFCE (2018). CO <sub>2</sub> , to air (from urea and urea-compounds application).
Lime application	CO <sub>2</sub>	IPCC 2006 Tier 1. Divided by years that lime is expected to have effect.	Compliant with FAO LEAP: EFs for CO <sub>2</sub> emissions from lime application shall be taken from IPCC (2006), Volume 4, 5 Chapter 11.
Land use change (LUC)	CO <sub>2</sub> , N <sub>2</sub> O-biogenic	Only included from purchased feed (depending on if included in source of LCI data)	FAO LEAP/PEFCE: LUC should be reported separately
Land use (LU)	CO <sub>2</sub> -biogenic	Not included in MVP.	FAO LEAP/PEFCE: C from soil due to land use shall be included and reported separately.
Fuel combustion	CO <sub>2</sub>	Fuel use is collected either as total farm fuel consumption or liter/ha. Data might also be collected by machinery computers tracking fuel consumption	PEFCE: field operations through total fuel consumption or through inputs of sub-farm units.
Pesticides	CO <sub>2</sub> , N <sub>2</sub> O	Data on active ingredient/ha is collected and multiplied by EF	PEFCE (2018). Pesticide emissions shall be modelled as specific active ingredients.
Drying and storage	CO <sub>2</sub>	Energy use for drying is estimated either by farm data or by using standard values for used energy per kg water dried	PEFCE (2018). Drying and storage shall always be included.
Seed input	CO <sub>2</sub> , N <sub>2</sub> O	Information on seed input as kg/ha and total area is collected.	PEFCE (2018). Input of seed material (kg/ha) shall be collected.
Fertiliser input	CO <sub>2</sub> , N <sub>2</sub> O	Type of fertiliser, amount of fertiliser (kg/ha) and N, P and K content is collected. EFs from fertiliser Europe are applied.	FAO LEAP: LCI data for production can be obtained from suppliers if available or can be collected from secondary databases.
Capital goods	CO <sub>2</sub>	Not included in MVP.	FAO LEAP: Capital goods with a lifetime greater than one year may be excluded; production and maintenance of machinery

Process	GHG	Method in Agrosfär	Guideline recommendation
			used in cultivation should be included. According to ISO and PEFCR dairy capital goods can be excluded.

Table 3. Most important method choices in animal model.

Process	GHG	Method in Agrosfär	Guideline recommendation
Animal energy requirements	Input to GHG calculations below	The method used in Norfor, i.e. another Tier 3 method than the one used in NIR.	FAO LEAP: Country-specific model used in NIR for the country in question, or alternative models which are peer reviewed, published and appropriate for the country in question.
Feed amounts consumed	CO <sub>2</sub> , N <sub>2</sub> O	Based on known feed inputs, assumed feed losses and calculated energy requirements, amounts of remaining feed inputs are calculated.	FAO LEAP: Feed consumption may be calculated from energy requirements. PEFCR: NIR should be guiding country-specific modelling.
Feed losses	CO <sub>2</sub> , N <sub>2</sub> O	Assumptions made for proportions of uneaten feed. Storage losses and losses due to e.g. mold were not included in the MVP	FAO LEAP: Feed losses have to be included.
Enteric fermentation	CH <sub>4</sub>	Country-specific calculation method according to Swedish NIR (corresponding to IPCC Tier 3).	FAO LEAP, IDF and PEFCR: minimum IPCC Tier 2.
Excreted amounts and amounts of N	Input to GHG calculations below	The method used in Norfor, i.e. another Tier 3 method than the one used in NIR.	FAO LEAP: IPCC Tier 2

Process	GHG	Method in Agrosfär	Guideline recommendation
Manure in stable and storage	CH <sub>4</sub>	Calculation method according to IPCC Tier 2 based on data/emission factors from Swedish NIR and from Norfor or IPCC.	FAO LEAP: IPCC Tier 2, with use of country-specific data and EF:s according to NIR.
Manure in stable and storage	Direct N <sub>2</sub> O	Based on excreted amounts of N. Emission factors from NIR, according to IPCC Tier 1.	FAO LEAP: IPCC Tier 1
Manure in stable, storage and pasture	Indirect N <sub>2</sub> O	Emissions of NH <sub>3</sub> estimated based on national data, then the IPCC Tier 1 emission factor was used to calculate the conversion to N <sub>2</sub> O.	FAO LEAP: IPCC Tier 1
Manure dropped on pasture	CH <sub>4</sub> , N <sub>2</sub> O	Use of IPCC Tier 2; IPCC default EF:s in combination with country-specific activity data.	FAO LEAP: IPCC Tier 1 for N <sub>2</sub> O and Tier 2 for CH <sub>4</sub> .
Bedding material	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	All bedding material is assumed to be straw. Bedding material is included in the calculation of emissions from manure in stable and storage. Production of straw is included in on-farm grain production, but purchased straw is not included in the MVP.	FAO LEAP: Only straw-specific steps, e.g. harvest, baling and transport should be included in the animal production (production up to harvest included in grain production).
Plastic for bailing of silage and straw	CO <sub>2</sub> , CH <sub>4</sub>	Not included in the MVP.	FAO LEAP: All inputs should be included, but straw is not specified.

Process	GHG	Method in Agrosfär	Guideline recommendation
Electricity and fuel used for animal production	CO <sub>2</sub> , CH <sub>4</sub>	All on-farm electricity and fuel use is on the crop production in the MVP.	FAO LEAP and PEFCR, in general: If possible, all inputs should be divided to reflect the actual use for different products/productions, otherwise allocation based on physical relationship between products should be made. If that is not possible, allocation based on other relationships should be made.

## 2.5 Allocation procedures

The general recommendation from several guidelines is to avoid allocation, if possible, by attributing emissions as far as possible to the product generating the emissions. When not possible, for example when one process generates several outputs, or when one input is used in several processes, the environmental burden (or benefit) of the input(s) must be allocated to the outputs in question. For some common processes allocation procedures are described, e.g. allocation between milk and meat. For other processes more general rules apply. ISO 14067 states that when allocation cannot be avoided allocation shall be done based on physical relationships between the outputs, for example based on mass, energy content or other physical relationships (International organization for standardization, ISO, 2018). When a physical relationship cannot be established, other relationships between outputs can be used, such as economic relationships (ISO 14067). The Agrosfär tool in general follows the ISO guidelines on allocation and uses specific allocation recommendations where applicable.

In the crop model allocation procedures are avoided as the model is built from a field level, meaning inputs will be directly collected at field level and emissions generated from the field are directly be coupled to the crop produced at the field. The field in this case can be considered a single production unit. In some cases, the output from one production unit might be several products, such as straw and grain. In that case no burden from crop production is allocated to the straw, but only the harvest and transportation of the straw itself. This is in line with the FAO LEAP guidelines (Food and Agriculture Organization of the United Nations (FAO), 2016).

For perennial crops which have several different life stages and where both generic and specific inputs occur at field level simultaneously, some modelling adjustments have been done to avoid allocation, more closely described in section 3.10. For green manure that generates benefits for several crops ahead in the crop rotation a custom-made solution has been developed following recommendations provided by FAO LEAP (see section 3.10).



A dairy farm usually produces both milk and animals for slaughter. As far as possible, activities generating emissions should be attributed to either milk or meat production. In cases where an activity is used both in milk and meat production and cannot be separated between the two, allocation is needed. For the allocation between milk and meat as products from a dairy farm, we have used the formula recommended by the IDF standard (European Dairy Association (EDA), 2018). The IDF allocation factor was originally related to the amount of milk sold expressed as fat and protein corrected milk (FPCM). However, ECM is the dominant form used in Sweden, and is used throughout the Agrosfär model. 1 kg ECM is approximately equivalent to 1.0077 kg FPCM. The empirically derived constant in the original IDF formula was 6.04. The constant was adjusted ( $6.04 / 1.0077 = 5.99$ ) in the Agrosfär model to represent ECM.

$$AF_{milk} = 1 - 5.99 * \frac{M_{meat}}{M_{milk}}$$

Where:

$AF_{milk}$  = The allocation factor for milk.

$M_{meat}$  = The total live weight (kg per year) of animals sold for breeding or slaughter. Animals that have died on the farm are excluded from  $M_{meat}$ .

$M_{milk}$  = The total amount of milk sold (as ECM, energy corrected milk, per year).

In this study, emissions from manure up to and including on-farm storage are included in the animal production system, while transport and emissions after application to arable land, as well as possible benefits and emissions from anaerobic fermentation or other off-farm treatments, are cut off from the animal production system. This is in line with the FAO LEAP and the PEFCR Dairy standards regarding manure without economic value, and where no activity after storage is included in the animal production system.

## 2.6 Climate modelling

### 2.6.1 Global warming potentials

Global warming potential (GWP) is one of the most used units for expressing climate impact in LCA. Characterisation factors are used to convert net emissions of different gases to a common, indicator value, CO<sub>2</sub>-equivalents.

Gases differ in their ability to absorb energy, that is, they have various impact on global warming. They also differ in their atmospheric residence times. Each gas has a specific global warming potential (GWP), which allows comparisons of the amount of energy the emissions of 1 tonne of a gas will absorb over a given time period, usually a 100-year averaging time, compared with the emissions of 1 tonne of CO<sub>2</sub>. The IPCC publishes characterisation factors for different greenhouse gases in synthesis reports, the fifth assessment report was issued in 2013, the sixth assessment report is expected in the latter half of 2022. As science progresses, the characterisation factors are modified. This is something to keep in mind when comparing LCA-results.

The chosen time horizon will influence the relative impact of different gases. Most commonly 100 years is chosen, and this is the recommended time period in most LCA-standards (ISO 14067, GHG protocols, PEF, PEF<sub>CR</sub> dairy, PEF<sub>CR</sub> feed, IDF).

For methane, IPCC publishes separate characterisation factors for fossil and biogenic emission sources. For fossil methane, the additional indirect effect from the oxidation of methane to CO<sub>2</sub> is included. This effect is captured to reflect the fact that methane will eventually break down to CO<sub>2</sub> in the atmosphere, and this CO<sub>2</sub> constitutes an additional burden to be attributed to the parent molecule, thus increasing the overall impact of a methane emission (Muñoz and Schmidt, 2016). Many LCA-standards (ISO 14067, GHG protocols, PEF, PEF<sub>CR</sub> dairy, PEF<sub>CR</sub> feed, IDF, GFLI) recommend separate treatment of biogenic and fossil methane.

IPCC also gives characterisation factors with and without feedback mechanisms. Feedback mechanisms are the indirect effects due to changes in climate, for example warming due to emissions of GHGs leads to increased amount of water vapor in the atmosphere, which in turn leads to further warming. GWPs with feedback can therefore give a fuller picture of the impacts but have a higher level of uncertainty. In many LCA-standards (ISO 14067, GHG protocols, PEF, IDF) it is recommended to use GWP<sub>100</sub> with feedback mechanisms.

In the Agrosfär model characterisation factors for GWP<sub>100</sub><sup>1</sup> is used, with assessment report 6 (AR6) IPCC 2021 as the default, with a possibility to switch to previous versions of IPCC (see Table 4). The greenhouse gases are reported separately in the model, and as total CO<sub>2</sub>-eq.

Table 4. Characterisation factors for GWP<sub>100</sub> is used, with IPCC 2021 as the default, the model gives a possibility to switch to previous versions of IPCC

	AR6, IPCC 2021 (default)	AR5, IPCC 2013 excluding cc- feedbacks	AR5, IPCC 2013 including cc- feedbacks
CO <sub>2</sub> biogenic	0	0	0
CO <sub>2</sub> fossil	1	1	1
CH <sub>4</sub> biogenic	27.2	28	34
CH <sub>4</sub> fossil	29.8	30	36
N <sub>2</sub> O	273	265	298

<sup>1</sup> Allen et al (2018) have described an alternative measure, GWP\*, which can be used to describe the consequences of changed emission levels of short-lived greenhouse gases related to historical or future emission levels. It can e.g. be used for evaluations of different emission scenarios based on historical and forecasted greenhouse gas emissions on global level. The Agrosfär model calculates the static current annual emissions on product level (in upcoming version also on farm level) where GWP\* is not a relevant measure (Landquist et al., 2019).

## 2.6.2 Biogenic carbon

In LCA it is often assumed that the carbon dioxide released from biogenic sources (e.g. from biomass uptake, respiration, combustion of biofuels) has no climate effect. This neutrality assumption is since all the carbon present in biomass has been taken up during photosynthesis. However, lately it has been argued that the biogenic carbon should be considered in climate calculations.

The issue of biogenic carbon accounting can be divided into three categories: (1) accounting of carbon flows, (2) reporting of biogenic carbon content and (3) assessing the climate impact of carbon storage/removal.

To start with, some LCA-standards (ISO 14067, GHG Protocol) state that all carbon flows shall be accounted for in the life cycle (Greenhouse Gas Protocol, 2011; International organization for standardization, ISO, 2018). By including e.g. the uptake of carbon from the atmosphere in crop cultivation and the release through respiration, decomposition or combustion in the same year, the climate impact will be zero. So why bother? Guinée et al. (2009) suggest that in LCAs of agricultural products, a distinction between “negative” and “positive” emissions may be relevant information, i.e. viewing the emissions as genuine cycles. It is important to note that some databases distinguish fossil CO<sub>2</sub> from biogenic CO<sub>2</sub>, but far from all, which means that it is a difficult task to follow these guidelines. It is therefore not included in the first version of Agrosfär.

Secondly, according to ISO 14067, reporting the biogenic carbon content is mandatory when performing cradle to gate studies, as this information may be relevant for the remaining value chain. This would for example for Agrosfär imply that the carbon content of crops, milk and beef should be reported. However, we see no immediate use for this type of information to the end users of Agrosfär and therefore chose to not include the carbon content of the products leaving the farm, in the first version of Agrosfär.

Thirdly, removing carbon from the atmosphere for a longer period of time can have a climate impact. For example, storage of carbon in wood constructions or soil carbon build up. In ISO 14067 it is stated that if more than 10 years between uptake and release, the climate impact should be included, but reported separately. PFCR on the other hand state that credits from 'temporary carbon storage' are excluded and that biogenic carbon emitted later than 100 years after its uptake is considered as permanent carbon storage. In the scientific literature, accounting for the time lag between uptake and release of biogenic carbon is an on-going debate and especially for the bioenergy sector the opinions differ (see e.g. Matušík & Kočí (2022)). In Agrosfär, we do not include climate impact of carbon storage in products. Storage of soil carbon (see section 2.7) is not included in the first version of the model, however carbon release from organic soils is included (see section 3.8).

## 2.7 Land use and land use change

Land use change (LUC) and land use (LU) can have an impact on soil carbon stocks. Land use change refers to the transformation of one land use category to another, e.g., transforming forest to cropland or cropland to grassland. LU refers to impact of land management practices to soil carbon stocks, such as tillage, addition of manure and crop rotation effects. A net increase of soil carbon stock is referred to as a removal of carbon from the atmosphere whereas a net decrease of soil carbon stock is referred to as an emission. Change in soil carbon stocks is accounted as biogenic carbon emissions or removals. If LUC and/or LU is included, it is often reported separately for transparency reasons.

LUC can be divided between direct land use change (dLUC) and indirect land use change (iLUC). Direct land use change occurs when non-agricultural land is converted to agricultural land for the purpose of producing an agricultural product, or input to the agricultural product, on that land. Indirect land use change is harder to distinguish, it is described as the event of converting non-agricultural land to agricultural land due to changes in agricultural practices elsewhere (European Commission, 2020).

Whether LUC or LU should be included in carbon footprint calculations varies between guidelines. According to FAO Leap, the impact of LUC is relevant to include if it occurred within 20 years of the assessment year and each year shall in that case carry 5% of the total LUC induced emissions (Food and Agriculture Organization of the United Nations (FAO), 2014). Changes occurring more than 20 years ago should not be included. According to ISO 14067, LUC shall be included whereas LU is not required (International organization for standardization, ISO, 2018). IDF recommends including LUC but not LU as changes in soil carbon under different managements is an ongoing field of research, there is a lack of data and broadly accepted methods (European Dairy Association (EDA), 2018). PEFCR refers to FAO LEAP, which recommends including both LUC and LU, while simultaneously highlighting the complexity of modelling LU.

Calculation of soil carbon dynamics requires a large amount of data and there is yet no simple and mainstreamed approach. Modelling soil carbon changes due to LU requires calculation models built on long term primary data and the models should be peer-reviewed and scientifically accepted. This type of models usually requires a high detail level of input data to yield relevant results. Further, to be able to credit carbon removals, an assurance of permanency needs to be provided, which is a challenge in changeable systems, such as agriculture.

Due to the complexity and difficulty in modelling changes in soil carbon stocks, soil organic carbon changes due to LU is not included in the first version of the Agrosfär tool but will be established in later versions if adequate models are developed and become acceptable within carbon accounting.

LUC is not calculated in the model for on-farm feed production. Swedish cropland has been decreasing since the 1950s and decreased by 30% during the period 1951-2015. Rather than expanding, cropland is being afforested or exploited and used for buildings, housing, and infrastructure. Land use change from expansion of agricultural land onto

forestland is not relevant for Swedish conditions (Statistics Sweden, 2019). However, if including a soil carbon tool in future versions of the model land use change will have to be considered for each farm as locally farmers might have cleared pasture or trees on their land to prepare cropland.

LUC is included for purchased and imported feed depending on the source of feed data. If included, it is reported separately.

Emissions of GHG occurring from cultivation and oxidation of organic soil is included, see chapter 3.

## 2.8 Uncertainties

The broadly defined concept of uncertainty includes two types: uncertainty and variability. Uncertainty (sometimes called “epistemic uncertainty”) is defined as incomplete or imprecise knowledge, and can be further subdivided into parameter, model, and scenario uncertainties. This type of uncertainty arises e.g. from uncertainty in data and emission factors, choice of models used to calculate emissions, and choice of system boundaries. These types of uncertainties can be reduced by increasing measurement accuracy, increasing model accuracy, and collecting data that better represent the system. Variability on the other hand can be defined as the inherent differences that cannot be reduced (e.g. variations in yields), but it can be represented more precisely if more information is available (Chen and Corson, 2014).

### 2.8.1 Standard recommendations

All standards taken into consideration in this project address the importance of describing confidence level and uncertainties in environmental footprint studies. The description shall follow the principles of relevance, accuracy, completeness, consistency and transparency. It should include methodological choices regarding use and end-of-life profile, allocation methods, source of global warming potential (GWP) values used and calculation models. Assumptions should be clearly described and in what way the assumptions could impact the results.

Data with high uncertainty can negatively impact the overall quality of the inventory. According to PEFCR, it is required to calculate a Data Quality Requirement index to address the uncertainties regarding data quality. This index should be based on representativeness of the analysed system concerning technology, geographical location, time and precision.

There are specific uncertainties addressed in the standards concerning the methodological choices, for example the GWPs for near term GHGs are not recommended to use. These addressed uncertainties have been taken into consideration in the methodological choices in this project.

## 2.8.2 Uncertainties in activity data

In the Agrosfär model, actual farm data is used to the largest extent possible; farmers can upload their data from a number of sources but can also manually enter data. There is of course a risk that some numbers are wrong, or that the farmers misinterpret what data is requested. For several of the input variables, there are min/max values in the model, so that unrealistic numbers cannot be entered.

## 2.8.3 Variations in results

It is always difficult to compare results from different climate calculation tools. Tools are developed for a specific purpose, and the methods, assumptions and input data are chosen to match the needs of the thought user. A tool developed for climate farm advisory services might therefore not be appropriate to use for product carbon foot printing.

Further, methods for calculations can vary depending on the detail level needed, and when it was developed. Emissions factors are constantly changing as science progresses, this is for example the case for characterisation factors to convert greenhouse gasses to CO<sub>2</sub>-equivalents, or emission factors to estimate nitrous oxide emissions from fields.

In Agrosfär a big benefit is the direct connection to farm specific data. This means that we might be able to see large variations in results between farms and between years. As the tool continues to be used, average results can be calculated over the years and results become less varied. Variations between farms can sometimes be due to natural variability i.e. due to inherent differences that cannot be reduced, for example a farm can have many fields with organic soils, which makes it difficult to compare results between different farms.

## 2.8.4 Uncertainties in emission factors

There are many emission factors included in the model, both related to the crop and the animal production calculations. Some emission factors are known to have a large impact on the results while at the same time being connected to large uncertainties, this is e.g. nitrous oxide emissions from cropping and emissions from manure deposited in pasture (Chen and Corson, 2014).

As an example of uncertainties in emission factors, a study by Flysjö et al. (2011) can be mentioned. They modelled a representative dairy farm in Sweden and estimated the influence of uncertainties in emission factors for enteric CH<sub>4</sub> emission and three N<sub>2</sub>O emission factors. For Swedish milk, the climate impact varied between 828 and 1560 kg CO<sub>2</sub>-eq. per 1000 kg energy-corrected milk.

The uncertainties related to emission factors can in other words be large. In the first version of Agrosfär, uncertainty ranges are not included. This could however be a future development.

## 2.8.5 Tests and validation of model

The Agrosfär model consist of many sub models and equations. To check that the model yields accurate results, several tests were performed, and results analysed for consistency. The crop production models are based on an a previously developed spreadsheet model, and several testcases could be run in both the spreadsheet and Agrosfär model to check that the results coincide. The animal model did not origin from an existing spreadsheet model and is more complex where different processes influence each other, making it difficult to check one parameter at a time in a spreadsheet. The test approach for the animal production is to use test data based on one animal's lifecycle, as well as the changes in a herd over one year.

## 3 Crop production

### 3.1 Methods

The crop production model builds on an already existing tool Dataväxt (Dataväxt, 2022). Dataväxt is primarily used as a crop production support tool, where crop production data is collected on field level. Data on yield level, amount and type of fertiliser, manure application (timing, type of manure, nutrient content and spreading technique), seed input, application rate of pesticides, field work, preceding crop, soil type are among data collected. This is the foundation of the ad-on climate calculating tool. The climate calculator in Dataväxt builds on these fields specific activity data and applies emission factors for calculating carbon footprints which are crop and field specific. Biogenic emissions, such as direct and indirect N<sub>2</sub>O emissions are calculated using the same activity data but applying equations and emission factors from IPCC. The results on field level can be aggregated to results on crop level, representing the average carbon footprint of each crop cultivated on the farm.

This model has been the foundation of the Agrosfär tool but with some modifications:

- Green manure
- Updated emission factors
- GHG emissions presented both on gas level (CH<sub>4</sub>, N<sub>2</sub>O and fossil CO<sub>2</sub>/biogenic CO<sub>2</sub>) and as CO<sub>2</sub>-eq.
- Impact on indirect N<sub>2</sub>O due to N volatilisation of manure spreading technique and how fast manure is incorporated into soil after spreading

The calculation is performed in seven steps, described in the following chapters.

### 3.2 Seed

Total climate impact from production of used seed is calculated based on use per hectare, area and emission factor of seed.

$$CI_{seed} = A \times \sum_n SI_n \times EF_{seed_n}$$

Where:

$CI_{seed}$ = Climate impact for production of used seed, [kg CO<sub>2</sub>], [kg N<sub>2</sub>O] and summarised as [kg CO<sub>2</sub>-eq.]

$A$ = Area of field [ha]

$SI_n$ = Input of seed type  $n$  [kg/ha]

$EF_{seed_n}$ = Emission factor of seed type  $n$ , [kg CO<sub>2</sub>/kg], [kg N<sub>2</sub>O /kg] and summarised as [kg CO<sub>2</sub>-eq./kg]



Emission factors for seed has been estimated from available data from life cycle analyses on cereals. For the varieties where data for seed production were lacking, the climate impact has been assumed to be 20% higher than the climate impact from cultivation of each variety. Share of N<sub>2</sub>O impact of total climate impact of seed production has been estimated to 40-60% of total GWP based on grain variety.

### 3.3 Fertilisers and lime

Total climate impact from production of used fertiliser and lime is calculated based on application rate per hectare, area and the emission factor of the raw materials.

$$CI_{fert.prod} = A \times \sum_n FI_n \times EF_{fertilizer_n}$$

$$CI_{lime.prod} = A \times \sum_n LI_n \times EF_{lime.prod_n}$$

Where:

$CI_{fert.prod}$  = Climate impact for production of applied fertiliser [kg CO<sub>2</sub>], [kg N<sub>2</sub>O] and summarised as [kg CO<sub>2</sub>-eq.]

$CI_{lime.prod}$  = Climate impact for production of applied lime, [kg CO<sub>2</sub>-eq.]

$A$  = Area of field [ha]

$FI_n$  = Application ratio of fertiliser type  $n$  [kg/ha]

$LI_n$  = Application ratio of lime type  $n$  [kg/ha]

$EF_{fertilizer_n}$  = Emission factor of fertiliser type  $n$ , [kg CO<sub>2</sub>/kg], [kg N<sub>2</sub>O/kg] and summarised as [kg CO<sub>2</sub>-eq./kg]

$EF_{lime.prod_n}$  = Emission factor of lime type  $n$ , [kg CO<sub>2</sub>-eq./kg]

The emission factor for mineral fertilisers have been taken from various sources

- Specific data for the mineral fertilisers are used where the climate calculation has been made available by the manufacturer
- When specific data did not exist, general data from (Fertilizers Europe, 2022) is used
- For mineral fertilisers where data on %N is included, the carbon footprint has been calculated based on N content
- If the country of manufacture is not stated in the name, the carbon footprint has been calculated assuming 70% Best Available Technique (BAT) with catalytic cleaning of N<sub>2</sub>O in production
- For fertiliser including N, climate impact from nitrous oxide and fossil carbon dioxide are reported separately, while the others are total in kg CO<sub>2</sub>-eq./kg

For biofertilisers, the climate impact from the production of the raw material has not been included, but only average impact from energy use in production and transport

For manure, no climate impact for production and storage is allocated to crop protection as this is allocated to animal husbandry'

For lime, general climate impact data from Fertilizers Europe (2022) is used. This is only reported in kg CO<sub>2</sub>-eq./kg.

To calculate the release of CO<sub>2</sub> in the field when spreading lime, general emission factors according to IPCC Tier 1 (Naturvårdsverket, 2021a) are used. The climate impact is distributed evenly over number of years that the liming covers (until the next liming is needed).

$$CI_{CO_2 \text{ from lime}} = A \times \sum_n (LI_n \times EF_{lime_n}) \times \frac{44}{12}$$

Where:

$CI_{CO_2 \text{ from lime}}$  = Climate impact from CO<sub>2</sub> emissions in field from liming, [kg CO<sub>2</sub>]

$A$  = Area of field [ha]

$LI_n$  = Application ratio of lime type  $n$  [kg/ha]

$EF_{lime_n}$  = Emission factor [kg C/kg], 0.12 for calcic limestone and 0.13 for calcic dolomite and Mg-lime (Naturvårdsverket, 2021a)

$\frac{44}{12}$  = Recalculation factor from kg elemental C to kg CO<sub>2</sub>

### 3.4 Crop protection

Total climate impact from production of used crop protection is calculated based on use per hectare, area and emission factor of crop protection based on area of use.

$$CI_{crop \text{ protection}} = A \times \sum_n CPI_n \times EF_{crop \text{ protection}_n}$$

Where:

$CI_{crop \text{ protection}}$  = Climate impact for production of used crop protection, [kg CO<sub>2</sub>-eq.]

$A$  = Area of field [ha]

$SI_n$  = Input of crop protection type  $n$  [kg/ha]

$EF_{crop \text{ protection}_n}$  = Emission factor of crop protection type  $n$ , [kg CO<sub>2</sub>-eq./kg]

Emission factors for crop protection are based on data from the Ecoinvent database (Wernet et al., 2016). Each plant protection is assigned an emission factor based on area of use.

### 3.5 Field work

Total climate impact from production of fuel and emissions from fuel use in field work is calculated based on fuel consumption per hectare, area and emission factor of fuel (well-to-wheel).

$$CI_{field\ work} = A \times \sum_n FI_n \times EF_{fuel_n}$$

Where:

$CI_{field\ work}$  = Climate impact for field work, [kg CO<sub>2</sub>-eq.]

$A$  = Area of field [ha]

$FI_n$  = Consumption of fuel type  $n$ , [l/ha] or [m<sup>3</sup>/ha]

$EF_{fuel_n}$  = Emission factor of fuel type  $n$ , [kg CO<sub>2</sub>-eq./l] or [kg CO<sub>2</sub>-eq./m<sup>3</sup>] (well-to-wheel)

Emission factors (well-to-wheel) for fuel are from Trafikverket /Energimyndigheten.

### 3.6 Direct nitrous oxide emissions from mineral soils

Direct nitrous oxide emissions are calculated according to the 2019 Refinement to the 2006 IPCC Guidelines (Hergoualc'h et al., 2019). Input to the calculation is variety of crop, soil content, harvest (yield), crop residues and applied amount of nitrogen.

Emissions from applied fertiliser are calculated using the aggregated emission factors in IPCC 2019 Tier 1, table 11.1

Emissions from applied mineral fertiliser:

$$CI_{N20\ min\ fert} = A \times \sum_n N_{min.\ fert_n} \times EF_{N20-N\ MF} \times \frac{44}{28} \times GWP_{N20}$$

Emissions from applied manure and organic fertiliser:

$$CI_{N2\ or\ fert} = A \times \sum_n N_{org.\ fert_n} \times EF_{N20-N} \times \frac{44}{28} \times GWP_{N20}$$

Where:

$CI_{N20\ min\ fert}$  = Climate impact from direct N<sub>2</sub>O emissions from mineral fertiliser, [kg CO<sub>2</sub>-eq.] and as [kg N<sub>2</sub>O] (removing GWP from equation)

$CI_{N20\ org\ fert}$  = Climate impact from direct N<sub>2</sub>O emissions from manure and organic fertiliser, [kg CO<sub>2</sub>-eq.] and as [kg N<sub>2</sub>O] (removing GWP from equation)

$A$	=	Area of field [ha]
$Nmin.fert_n$	=	Application ratio of N in mineral fertiliser type $n$ [kg/ha]
$Nmin.fert_n$	=	Application ratio of N in manure or organic fertiliser type $n$ [kg/ha]
$EF_{N_2O-N}$	=	Emission factor for N in fertiliser and manure [kg N <sub>2</sub> O–N /kg N], set to 1% for all types of fertilisers, manure and crop residues (aggregated emission factors in IPCC 2019 Tier 1, table 11.1)
$\frac{44}{28}$	=	Recalculation factor from kg N <sub>2</sub> O–N to kg N <sub>2</sub> O
$GWP_{N_2O}$	=	Global Warming Potential 100 y for N <sub>2</sub> O, [kg CO <sub>2</sub> -eq./kg N <sub>2</sub> O] set to 273 according to IPCC AR6, 2021

To calculate the N<sub>2</sub>O emissions from above and below ground crop residues, the amounts of above and below ground crop residues are first calculated. Above ground residues are calculated using the alternative method as stated in IPCC 2019, table 11.2

$$AGR_{DM} = Y_{DM} \times Slope_n + Intercept_n$$

Below ground residues are calculated using the Ratio of below-ground biomass to above-ground biomass in IPCC 2019, table 11.1A

$$BGR_{DM} = AGR_{DM} \times RS_n$$

Where:

$AGR_{DM}$	=	Above ground residue [kg dry matter/ha]
$Y_{DM}$	=	Dry matter yield of harvested crop [kg dry matter/ha]. Dry matter yield can be reported in Agrosfär. If only fresh yield of harvested crop is reported the dry matter yield can be calculated using the Dry matter fraction of harvested product for the crop according to IPCC 2019, table 11.1A
$Slope_n$	=	Slope of crop type $n$ [-] according to IPCC 2019, table 11.2
$Intercept_n$	=	Intercept of crop type $n$ [kg dry matter/ha] according to IPCC 2019, table 11.2
$BGR_{DM}$	=	Below ground residue [kg dry matter/ha]
$RS_n$	=	Ratio of below-ground biomass to above-ground biomass of crop type $n$ [-] according to IPCC 2019, table 11.1A

Emissions from crop residues are then calculated using the aggregated emission factors in IPCC 2019 Tier 1, table 11.1

$$CI_{N_2 \text{ residues}} = ((AGR_{DM} \times (1 - Frac_{Remove}) \times EF_{N_2O-N}) + (BGR_{DM} \times EF_{N_2O-N})) \times A \times \frac{44}{28} \times GWP_{N_2O}$$

Where:

$CI_{N2O\ residues}$	= Climate impact from direct $N_2O$ emissions from crop residues, [kg $CO_2$ -eq.] and as [kg $N_2O$ ] (removing GWP from equation)
$AGR_{DM}$	= Above ground residue [kg dry matter/ha]
$Frac_{Remove}$	= Fraction of above-ground residues removed [mass %]. Fraction removed can be reported as a specific figure in Agrosfär or as a Yes/No question. Yes = 50% of crop residues are considered removed. No = 0% crop residues are considered removed.
$EF_{N2O-N}$	= Emission factor for N in fertiliser and manure [kg $N_2O-N$ /kg N], set to 1% for all types of fertilisers, manure and crop residues (aggregated emission factors in IPCC 2019 Tier 1, table 11.1)
$BGR_{DM}$	= Below ground residue [kg dry matter/ha]
$A$	= Area of field [ha]
$\frac{44}{28}$	= Recalculation factor from kg $N_2O-N$ to kg $N_2O$
$GWP_{N2}$	= Global Warming Potential 100 y for $N_2O$ , [kg $CO_2$ -eq./kg $N_2O$ ] set to 273 according to IPCC AR6, 2021

Finally, the emissions from mineral fertilisers, manure, organic fertilisers and crop residues are added together

$$CI_{N2O\ direct} = CI_{N2O\ min\ fert} + CI_{N2O\ org\ fert} + CI_{N2O\ residues}$$

## 3.7 Indirect nitrous oxide emissions

Indirect nitrous oxide emissions are calculated based on crop, municipality, soil type, nitrogen content,  $NH_4-N$  in manure, date of application of manure including timing, spreading technique and how fast manure is incorporated into soil after spreading. Ploughing date after harvest and use of any catch crop is also considered. The calculation is based on the calculation methods used in the VERA tool, and the Odlingperspektiv calculation model used by Greppa Näringen (Bertilsson and Nilsson, n.d.).

The calculation of indirect  $N_2O$  leaching is divided into two parts,

- Indirect  $N_2O$  due to N leaching/runoff
- Indirect  $N_2O$  due to N volatilisation

### 3.7.1 Indirect $N_2O$ emissions due to N leaching/runoff

The calculation of indirect  $N_2O$  emissions due to N leaching/runoff is made in six steps described below.

### Standard leaching/run-off – location based

A standard N leaching/run-off is calculated based on the geography and soil type. For each field in Agrosfär the location in form of municipality and the soil type is given. The standard leaching for the municipality and soil type is looked up in a table originally published in Aronsson and Torstensson (2004).

$$N_{leach\ std} = VLOOKUP \left( Municipality_n; STDleach\_table(MATCH(Soil\_type_n)) \right)$$

Where:

$N_{leach\ std}$  = Standard N leaching from field  $n$ , [kg N/ha]

$Municipality_n$  = Name of municipality where field  $n$  is situated

$STDleach\_table$  = Table with standard leaching data according to Aronsson and Torstensson (2004)

$Soil\_type_n$  = Name of soil type of field  $n$

### Crop specific adjustment

An adjustment factor based on the type of crop growing at the field is calculated using a table from VERA/Odlingsperspektiv

$$F_{leach\ crop,n} = VLOOKUP(Crop_n; Cropleach\_table)$$

Where:

$F_{leach\ crop,n}$  = Adjustment factor for crop  $n$ , [-]

$Crop_n$  = Name of crop type  $n$

$STDleach\_table$  = Table with crop leaching factors from Odlingsperspektiv

### Reduction tillage

The possible reduction of leaching depending on the time of the next tillage after harvest and type of crop is calculated in a table from VERA/Odlingsperspektiv.

$$F_{leach\ till,n} = VLOOKUP \left( Till\_time_n; Till\_time\_table(MATCH(Crop_n)) \right)$$

Where:

$F_{leach\ till,n}$  = Tilling time reduction factor for field  $n$ , [-]

$Till\_time_n$  = Time for tilling after harvest in field  $n$ , [m-d]

$Till\_time\_table$  = Table with tilling time reduction factor from Odlingsperspektiv

$Crop_n$  = Name of crop in field  $n$

### Reduction catch-crop

The possible reduction of leaching by growing catch crop in the field depending on the tilling time calculated in a table from VERA/Odlingsperspektiv

$$F_{leac\ c\_crop,n} = VLOOKUP(Crop\_type_n; C\_crop\_table(MATCH(Till\_time_n)))$$

Where:

$F_{leac\ c\_crop,n}$  = Catch crop reduction factor for field  $n$ , [-]

$Crop\_type_n$  = Name of type of crop in field  $n$

$C\_crop\_table$  = Table with catch crop reduction factor from Odlingsperspektiv

$Till\_time_n$  = Time for tilling after harvest in field  $n$ , [m-d]

### Application of manure

The possible increased leaching due to the application of manure is calculated using tables from VERA/Odlingsperspektiv based on time of application of manure, crop type and soil type

$$\begin{aligned} N_{leac\ man\_type,n} &= VLOOKUP(Man_n; Man\_s\_table(MATCH(Soil\_type_n))) \times TM_n \\ F_{leac\ man\_time,n} &= VLOOKUP(Man_n; Man\_t\_table(MATCH(Crop\_type_n; Ap\_t_n))) \\ N_{leac\ manure} &= \sum_n (N_{leac\ man\_type,n} \times F_{leac\ man\_time,n}) \end{aligned}$$

Where:

$N_{leac\ man\_type,n}$  = Basic leaching of application of manure type  $n$  on soil type  $n$ , [kg N/ha]

$Man_n$  = Name of manure in field  $n$

$Man\_s\_table$  = Table with basic leaching data from manure type vs soil type from Odlingsperspektiv

$Soil\_type_n$  = Name of soil type in field  $n$

$TM_n$  = Applied tonnage of manure in field  $n$  [ton/ha]

$F_{leac\ man\_time,n}$  = Application factor of manure  $n$  at application time  $n$

$Man\_t\_table$  = Application factor manure type vs type of crop and application time from Odlingsperspektiv

$Ap\_t_n$  = Application time of manure in field  $n$

$N_{leac\ manure}$  = Leaching from application of manure, [kg N/ha]

### Total Indirect N<sub>2</sub>O due to N leaching/run-off

The basic leaching and the different adjustments described above are summarised the emission factor for leaching/runoff from IPCC 2019 table 11.3 is used to calculate the N<sub>2</sub>O emission

$$CI_{N_2 \text{ ind\_leach}} = A \times EF_{N_2O-N} \times \frac{44}{28} \times GWP_{N_2} \times \left( (N_{leac \text{ std}} \times (1 + F_{leach \text{ crop},n})) \times (F_{le \text{ till},n} + F_{leach \text{ till},n} \times (F_{leach \text{ c\_crop},n} - 1)) + N_{leach \text{ manure}} \right)$$

Where:

$CI_{N_2 \text{ ind\_leach}}$  = Climate impact from indirect N leaching/runoff, [kg CO<sub>2</sub>-eq.] and as [kg N<sub>2</sub>O] (removing GWP from equation)

$A$  = Area of field [ha]

$EF_{N_2O-N}$  = Emission factor for leaching/runoff from [kg N<sub>2</sub>O-N /kg N], set to 1.1% in IPCC 2019 Tier 1, table 11.3

$\frac{44}{28}$  = Recalculation factor from kg N<sub>2</sub>O-N to kg N<sub>2</sub>O

$GWP_{N_2}$  = Global Warming Potential 100 y for N<sub>2</sub>O, [kg CO<sub>2</sub>-eq./kg N<sub>2</sub>O] set to 273 according to IPCC AR6, 2021

### 3.7.2 Indirect N<sub>2</sub>O emissions due to N volatilisation

The calculation of indirect N<sub>2</sub>O emissions from N volatilisation is made in accordance with IPCC 2019 Tier 2. For manure application N volatilisation specific Swedish emission factors are applied based on Karlsson and Rhode (2002). The Swedish emission factors consider timing, spreading technique and how fast manure is incorporated into soil after spreading.

Ammonium volatilisation from N in applied mineral fertiliser is calculated based on application rate per hectare, area and the emission factor of the fertiliser.

$$AV_{NH_3-N \text{ min fert}} = \sum_n N_{min. \text{ fert}_n} \times EF_{NH_3-N \text{ MF}}$$

Where:

$AV_{NH_3-N \text{ min fert}}$  = Ammonium volatilisation from applied N in mineral fertiliser, [kg NH<sub>3</sub>-N/ha]

$N_{min. \text{ fert}_n}$  = Application ratio of N in mineral fertiliser type  $n$  [kg/ha]



$EF_{NH_3-N\ MF}$  = Emission factor for N in fertiliser and manure [kg NH<sub>3</sub>-N/kg N], set to 1.2%, average value according to Swedish NIR 2021

Ammonium volatilisation form N in applied manure is calculated based on application rate per hectare, NH-N rate in manure and the loss in spreading in relation to timing, spreading technique and how fast manure is incorporated into soil after spreading.

$$AV_{NH_3-N\ man} = \sum_n \left( Nman_n \times R_{NH-N\ Man,n} \times VLOOKUP \left( Man_n; Man\_Av\_table \left( MATCH(MS\_tech_n; MS\_time_n; Ap\_t_n) \right) \right) \right)$$

Where:

$AV_{NH_3-N\ man}$  = Ammonium volatilisation from applied N in manure, [kg NH<sub>3</sub>-N/ha]

$Nman_n$  = Application ratio of N in manure type  $n$  [kg/ha]

$R_{NH-N\ Man,n}$  = NH-N/ N rate in manure type  $n$ , [kg NH-N /kg N]

$Man_n$  = Name of manure type  $n$

$Man\_Av\_table$  = Table with N-loss data from manure type in relation to timing, spreading technique and how fast manure is incorporated into soil after spreading from Karlsson & Rhode (2002), [kg NH<sub>3</sub>-N /kg NH-N]

$MS\_tech_n$  = Name of spreading technique of manure type  $n$

$MS\_time_n$  = Time of incorporation into soil after spreading of manure type  $n$

$Ap\_t_n$  = Application time of manure in field  $n$

Ammonium volatilisation form N in applied mineral fertiliser and manure are then summarised and the emission factor for volatilisation and redeposition from IPCC 2019 table 11.3 is used to calculate the N<sub>2</sub>O emission.

$$CI_{N_2O\ AV} = A \times EF_{N_2O-NH} \times \frac{44}{28} \times GWP_{N_2O} \times (AV_{NH_3-N\ min\ fert} + AV_{NH_3-N\ man})$$

Where:

$CI_{N_2O\ AV}$  = Climate impact from ammonium volatilisation and redeposition, [kg CO<sub>2</sub>-eq.] and as [kg N<sub>2</sub>O] (removing GWP form equation)

$A$  = Area of field [ha]

$EF_{N_2O-N}$  = Emission factor for volatilisation and redeposition from [kg N<sub>2</sub>O-N /kg NH<sub>3</sub>-N], set to 1.0% in IPCC 2019 Tier 1, table 11.3

$\frac{44}{28}$ =	Recalculation factor from kg N <sub>2</sub> O–N to kg N <sub>2</sub> O
$GWP_{N20}$ =	Global Warming Potential 100 y for N <sub>2</sub> O, [kg CO <sub>2</sub> -eq./kg N <sub>2</sub> O] set to 273 according to IPCC AR6, 2021

### 3.7.3 Total indirect N<sub>2</sub>O emissions

Indirect N<sub>2</sub>O emissions due N leaching/runoff and volatilisation are then summarised to get the total indirect N<sub>2</sub>O emissions.

$$CI_{N20\ indirect} = CI_{N20\ ind\_leac} + CI_{N20\ AV}$$

## 3.8 Greenhouse gas emissions from organic soils

Drained organic soils are a source of CO<sub>2</sub> and N<sub>2</sub>O emissions due to oxidation induced by drainage. Hectares of managed or drained organic soils are multiplied by a default emission factor. In the tool soils with above 40% in mulch are considered as organic soils. The emission factors for organic soil applied in the tool are in line with the emission factors used in the Swedish national inventory (Naturvårdsverket, 2021a). For cropland, the CO<sub>2</sub> emission factor is derived from IPCC Wetland supplement (Hiraishi et al., 2014) but reworked by Lindgren and Lundblad (2014) to include results only from countries with similar climatic conditions as Sweden. For N<sub>2</sub>O emissions from cropland on organic soil, the emission factor is derived from IPCC without adjustments.

The emission from organic soils is calculated using the following equations:

$$CI_{Org\_N2O} = IF(Mulch > 40\% ; A \times EF_{Org\_N2O-N} \times \frac{44}{28} \times GWP_{N20}; 0)$$

$$CI_{Org\_CO2} = IF(Mulch > 40\% ; A \times (EF_{Org\_CO2\_atm} + EF_{Org\_CO2\_diss}) \times \frac{44}{12}; 0)$$

$$CI_{Org} = CI_{Org\_N2O} + CI_{Org\_CO}$$

Where:

$CI_{Org\_N2O}$  = Climate impact from N<sub>2</sub>O emission form organic soils, [kg CO<sub>2</sub>-eq.] and as [kg N<sub>2</sub>O] (removing GWP form equation)

$Mulch$ = Mulch content in soil [mass-%]

$A$ = Area of field [ha]

$EF_{Org\_N2O-N}$ =Emission factor for CO<sub>2</sub> emission from organic soils [kg N<sub>2</sub>O–N/ha,y], set to 13 in Swedish NIR 2021, Annex 1 pg 136-137

$\frac{44}{28}$ = Recalculation factor from kg N<sub>2</sub>O–N to kg N<sub>2</sub>O

$GWP_{N20}$  = Global Warming Potential 100 y for  $N_2O$ , [kg  $CO_2$ -eq./kg  $N_2O$ ]  
set to 273 according to IPCC AR6, 2021

$CI_{Org\_CO2}$  = Climate impact from  $CO_2$  emission from organic soils, [kg  $CO_2$ -eq.]

$EF_{Org\_CO2\_atm}$  = Emission factor for  $CO_2$  loss to the atmosphere from organic soils [kg  $CO_2$ -C/ha,y], set to 6.1 in Swedish NIR 2021, Annex 1 pg 136-137

$EF_{Org\_CO2\_atm}$  = Emission factor for loss of dissolved carbon from organic soils [kg  $CO_2$ -C/ha,y], set to 0.12 in Swedish NIR 2021, Annex 1 pg 136-137

$CI_{Org}$  = Total climate impact from organic soils, [kg  $CO_2$ -eq.]

For further information on organic soils, see Appendix 1.

### 3.9 Crop drying

Total climate impact from drying is calculated either from measured electricity and fuel consumption in the dryer or estimated based on standard energy consumption in drying and dry matter content in the crops before and after the drier. In both cases type of fuel and source of electricity is needed and in the later case also the yield from the field/ the mass of crop dried.

Case 1, known electricity and fuel consumption

$$CI_{tot\_dry} = \sum_n CF_{dry_n} \times EF_{fuel_n} + \sum_m CE_{dry_m} \times EF_{el_m}$$

Case 2, based on dry matter

$$CI_{tot\_dry} = A \times Y_{fresh} \times \left( SCF_{dry} \times \left( \frac{1 - DM_{wet}}{1 - DM_{dry}} \right) \times EF_{fuel_n} + SCE_{dry} \times EF_{el_m} \right)$$

Where:

$CI_{tot\_dry}$  = Total climate impact for drying, [kg  $CO_2$ -eq.]

$CF_{dry}$  = Measured fuel consumption of drying, [MWh].

$CE_{dry}$  = Measured electricity consumption of drying, [MWh]

$SCF_{dry}$  = Standard fuel consumption of drying, [MWh/ton water]. Set to 0.14 based on the assumption that it takes 0.15 l of fuel oil to dry 1 kg of water

$DM_{wet}$  = Dry matter in crop before dryer [mass %]

$DM_{dry}$  = Dry matter in crop after dryer [mass %]

$EF_{fuel_n}$  = Emission factor of fuel type  $n$ , [kg  $CO_2$ -eq./MWh]

$SCEdry$  = Standard electricity consumption of drying, [MWh/ton crop], set to 0.019

$EF_{fuel_n}$  = Emission factor of electricity source  $m$ , [kg CO<sub>2</sub>-eq./MWh]

$Y_{fresh}$  = Fresh Yield of harvested crop [ton/ha]

$A_n$  = Area of field [ha]

Emission factors for fuel and electricity are from Energimyndigheten.

## 3.10 Perennial crops

Perennial crops and grass crops are crops with a life cycle spanning over several years, including different life stages. The life stages can include a juvenile stage (establishment year), a period of maximum production and a period of decline in production. Only looking at one year and field at a time will give a product with a high climate impact in the juvenile stage when production is low, and a lower climate impact when production is high. PEFCR feed and FAO LEAP recommend that all life cycle stages of a perennial crop should be included and averaged, meaning that all development stages are proportionally represented in the studied period. If the different life stages are known to be disproportional it is recommended to make a correction by adjusting the crop areas allocated to different life stages to a theoretical steady state (European Commission, 2020; Food and Agriculture Organization of the United Nations (FAO), 2016). Assuming a steady state situation where all production stages and generic inputs are proportionally distributed will give an averaged climate impact for the output which will not differ year to year due to different life stages being overrepresented.

*Solution in the Agrosfär tool:* In the tool no correction will be made to reach a theoretical steady state. An argument for this is that in the Agrosfär tool all the emissions from inputs (except for field work) and biogenic emissions are divided over the lifetime of the perennial crop. If the perennial crop has a lifetime of three years, the emissions will be divided by the number of years and equally distributed over the years. Emissions from field work (production of fuel and emissions from burning fuels) is allocated to the single field. By including all fields with perennial crops at the farm, the average will over time be close to a theoretical steady state where all production stages are represented. Each assessment year will include some fields where grass crops are established, fields with maximum production and fields with declining production which are tilled and re-sown. The final climate impact will be an average of all the fields, thus including all the production stages.

## 3.11 Green manure

According to FAO LEAP feed supply chains green manure can be categorised as a generic input and emission at field level. It is an input that cover several production cycles and

generates benefits for the whole crop rotation (i.e. not only the crop which it is sown into or before) even if the input occurs in only one year (Food and Agriculture Organization of the United Nations (FAO), 2016). This can be handled by averaging out inputs over all fields in the rotation, without considering complex bio-physical relations.

***Solution in the Agrosfär tool:*** In the Agrosfär tool the biogenic emissions caused by green manure are calculated based on a fictive yield, as the green manure is not harvested instead the biomass is ploughed down in the field. Users of the tool can thus choose an option stating that the current crop is a green manure crop and that no biomass is removed from the field. The user can state a fictive yield, which is the foundation for calculating direct and indirect dinitrogen oxide emissions. The emissions are attributed to the single field where the green manure is grown, and thus allocated to the crops grown at the field the coming years, based on the number of years that the user estimates that the green manure will have a nitrogen effect, up to a maximum of five years. This approach is more appropriate than allocation of the emissions to all the crops in the crop rotation, as some crops might never benefit from the nitrogen provided by green manure.

## 4 Pasture

Sweden has a tradition of managing semi-natural pastures with a relatively high number of trees and bushes. Some of the typical habitats also have low fodder value but have a high biodiversity value. As well as being very important for nature conservation, they are considered a significant and valued element of the cultural heritage in Sweden. These types of pastures are generally not fertilised or ploughed. In the Agrosfär model, the emissions caused by animal manure during grazing ( $\text{CH}_4$  and direct  $\text{N}_2\text{O}$ ) on these permanent grasslands is included in the animal production model. There could be other nitrous oxide emissions e.g. from decomposition of roots or indirectly from nitrogen leaching, however as these grasslands are nutrient poor, we can expect these emissions to be very low and are therefore not included in the model. Further, emissions from more carbon and nutrient rich semi-natural pastures are not included in the first version of Agrosfär.

Animals also graze on the regrowth of grasslands used for silage production. In these cases, the emissions caused by animal manure during grazing ( $\text{CH}_4$  and direct  $\text{N}_2\text{O}$ ) is included in the animal production model. As the field is used for silage, emissions from field work and nitrous oxide emissions from soil are included in the crop production model.

## 5 Animal husbandry

Emissions from livestock (enteric fermentation) and manure management are calculated and organised in the same way in the Agrosfär model as in the IPCCs Guidelines for Greenhouse Gas Inventory, Volume 4 Agriculture, Forestry and Other Land Use, chapter 10 (Gavrilova et al., 2019). Many LCA and CF, including the IDF guide to CF for the dairy industry, refer to IPCC guidelines for guidance on how to calculate greenhouse gas (GHG) emissions.

Data on livestock population, e.g. number of heads, animal weight and weight gain, and feed characteristics is used to estimate feed requirements (net energy [MJ NE] per animal per day or year). The heavier the animal and/or higher the weight gain, the higher the feed requirements.

The calculated feed requirements and data on feed characteristics is then used to estimate methane emissions from enteric fermentation. The higher the feed requirements and/or the poorer the feed quality, the higher the methane emission.

Greenhouse gas emissions from on-farm feed production were modelled in the crop production module and imported to the animal production module. Data on carbon footprints of purchased feeds were adopted from Swedish feed suppliers' databases.

Emissions from manure management is assessed based on data on feed requirements and feed characteristics, and data on current manure management systems. Data on feed characteristics and feed requirements is used to calculate the amount of nitrogen (N) and volatile solids (VS) excreted in manure. Data on N and VS content in the manure and information about the manure management system is then used to calculate N<sub>2</sub>O and CH<sub>4</sub> emissions from manure management.

### 5.1.1 Motives to choose the applied methods

The IDF guidelines on Carbon Footprint for the dairy industry states that at least a Tier 2 approach is necessary for the assessment of enteric fermentation (6.2) (International Dairy Federation (IDF), 2015). The IPCC guidelines provide a detailed Tier 2 method to estimate energy requirement and emissions from enteric fermentation and manure management.

More advanced Tier 3-approaches for feed requirement and enteric fermentation can be found in The Swedish National Inventory Report (NIR) and the documentation of the Norfor system, the Nordic feed evaluation system (Naturvårdsverket, 2021a; Norfor, 2022; Volden, 2011).

#### **Energy requirements of cattle:**

Sweden has adopted a country specific method in NIR to estimate energy requirements for all cattle categories (Naturvårdsverket, 2021a). It is based on methods and feed evaluation that have been used in Sweden for a long time. The assumptions and methods used in NIR are presented in Bertilsson (2016). Energy requirements are calculated as in Spörndly (2003), "*Blå boken*". Energy content of feed and animal requirements are

expressed as MJ metabolizable energy (MJ ME). In NIR, energy intake is eventually recalculated to MJ gross energy (MJ GE) to harmonise with IPCC's reporting requirements. An advantage of the NIR method is that it has been reviewed and approved by a reputable body; any country specific methods used in NIR must be approved by UNFCCC (United Nations Framework Convention on Climate Change).

Norfor is the new feed evaluation system developed for the Nordic countries. Norfor is based on thorough research and contains many detailed estimations and equations that stem from scientific papers. The Norfor system is documented in *Gröna boken* (Volden, 2011), and the equations and dataset (e.g. feed tables) are continuously updated (Norfor, 2022).

An important difference between the Norfor system and *Blå boken* is that energy requirements are estimated and expressed as net energy (NE) in Norfor instead of metabolizable energy as in NIR. Norfor is implemented in advisory tools (IndividRAM och FoderOpti), and net energy content of feeds is included in feed analyses. However, some other advisory tools/feed planning tools are still based on *blå boken* and MJ ME.

Equations from the Norfor system is implemented in the Agrosfär model to estimate energy requirements. Main reasons for choosing the Norfor system over *Blå boken* and NIR are:

- The Norfor system is more advanced and detailed than *Blå boken*.
- The Norfor system is the new feed evaluation system that is implemented in major advisory tools (IndividRAM and FoderOpti).
- The Norfor system is updated continuously.
- Equations from Norfor can also be used to estimate excretion rates (N and VS in manure, see below), whereas estimations of energy requirements and excretion rates are not correlated in NIR.
- Enables better comparability with estimations of GHG emissions in IndividRAM.

Estimates of energy requirements are to a large extent based on the same parameters (e.g. weight, weight gain) in *Blå boken* and Norfor as in the IPCC guidelines. Hence, the same trends can be expected with any of these methods. For example, the heavier the animal and higher the weight gain, the higher the energy requirement. However, energy requirements are expressed in different units: Metabolizable energy in *Blå boken*, and Net energy in Norfor and in the IPCC guidelines. Hence, the results (MJ per animal per day) can't be compared without conversion.

### **Enteric fermentation of cattle:**

Methane from enteric fermentation of cattle is calculated by the same equations in the Agrosfär model as in NIR. Sweden has adopted a country specific method in NIR for methane from enteric fermentation of cattle (Bertilsson, 2016). There are separate equations for cows and growing cattle. The equations implemented in NIR was previously used in Norfor. The equations in Norfor has been updated recently (Norfor, 2022).



However, the updates are not implemented in the Agrosfär model since the updated equation for growing cattle contains a parameter (rumen degraded NDF, rd\_NDF) that is not readily available in the Agrosfär model. rd\_NDF is estimated based on a set of sub-equations that describes the degradation of NDF in the rumen and intestines, which requires detailed information on feeds, feeding regime and animal parameters. In addition, the updated equation for growing cattle does not seem to be scientifically reviewed, whereas the NIR method has been approved by UNFCCC.

### **Manure management of cattle manure:**

Estimations of N and VS excretion rates from cattle are based on equations from the Norfor system (Norfor, 2022; Volden, 2011). The excretion rates are thereby correlated to the estimated energy requirements of the animals. The Norfor system is chosen over the IPCC guidelines because of the consistency with the estimation of energy requirement and the Norfor system provides a more detailed estimation of excretion rates than the IPCC guidelines Tier 2.

The Swedish NIR contains country specific methods to estimate excretion rates from cattle. However, these methods cannot be used in the Agrosfär model. In the Swedish NIR, data on N and VS content in cattle manure is provided by the Swedish Board of Agriculture. The specific data sets or equations used by the Swedish Board of Agriculture are not specified in NIR or, to our knowledge, publicly elsewhere. In addition, the estimates of excretion rates (N and VS content in cattle manure) are not derived from the energy requirements calculated in NIR, and it seems as if these two estimations are not correlated.

For methane and direct nitrous oxide emissions from manure storage, the IPCC Tier 2 method was used. Emission factors based on country-specific data according to the Swedish NIR were used for methane from slurry, while the IPCC default emission factors were used for methane from solid manure as well as direct nitrous oxide emissions from all types of manure. This is in accordance with the recommendations in the FAO LEAP standard.

Emission factors for ammonia (indirect nitrous oxide) comes from the advising tool VERA. VERA is developed by the Swedish Board of Agriculture/Greppa Näringen, and the tool is commonly used by advisor to assess farm-scale ammonia emissions from stable, storage and spreading of manure. The Swedish NIR contains country specific method to assess ammonia emissions based on the national reporting of air pollutants (Naturvårdsverket, 2021a). However, the emission factors applied in NIR are not as detailed as in VERA, and they don't reflect differences in e.g. coverage of manure storage.

## 5.2 Livestock population

### 5.2.1 Time frame and scope

The assessment comprises 1 year, from January 1 to December 31.

The assessment comprises all cattle that lived on the farm during the year. All cattle that lived there the entire year or part of the year (e.g. calves born during the year).

The calculations are carried out per head and day, and the results are then aggregated as total emission per livestock population and year.

### 5.2.2 Livestock categories

The following livestock categories are applied:

- Cows:
  - **Dairy cows.** Cows that have calved at least once and are used principally for milk production. Dairy cows are further subdivided into Lactating (dairy) cows and Dry cows.
  - **Beef cows.** Cows used to produce offspring for meat. A cow is defined as Beef cow if she is of beef breed and there is no registration of her milk yield.
- Growing cattle. From birth until the animal is slaughtered or the heifer calves for the first time. Dairy and beef breeds are not separated.
  - **Heifers.**
  - **Bulls.** Intact males. Includes growing bulls and bulls for breeding purposes
  - **Steers.** Castrated males. Castrated males are considered to be steers from birth although they are born as bulls. They are castrated at such young age that this generalisation is deemed appropriate.

### 5.2.3 Breeds and purpose of the animal

Breed is used to determine breed-specific default values (e.g. body weight at birth and as mature) and to identify individuals as dairy or beef cattle. Distinction between dairy and beef breed is needed to ensure that the right coefficients are applied, for example for the estimation of energy requirement of bulls and methane emissions from manure from cows.

The breed of an animal can be derived from “*Min gård*” (a system provided by Växa) and/or CDB (the central register of bovine animals, administrated by the Swedish Board of Agriculture). Each breed has a unique number code in CDB, e.g. Simmental = 14. The documentation of Norfor contains default values on body weights for a variety of common breeds, but not as many breeds as in CDB. It is assumed that default body weights of breeds that are not described in Norfor can be estimated as the weight of similar breeds described in Norfor. An example: “SKB (*Svensk kullig boskap*)” is a small dairy breed that is included in CDB, but not in Norfor (2022). It is assumed that SKB is equivalent to Jersey.

However, many cattle are crossbreeds (code 99), and they can't automatically be identified as dairy or beef breed. Additional information is needed to identify a crossbreed as dairy or beef breed. This information can be derived manually by the farmer or to extent automatically for example based on body weights.

Cows of some breeds are always defined as Dairy cows (e.g. Jersey) or as Beef cows (e.g. Highland Cattle). But the breed may not always be sufficient to determine if the cow is used for milk production or not. There are breeds mainly used for beef production, but can be used in milk production as well (e.g. Simmental). There are cows of dairy breed that are not milked but used to raise calves. The following information is used to define a cow as Dairy or Beef cow:

- Dairy cows are defined as cows that are milked. This is true if her milk yield is registered or the farmer states that all cows are used for milk production.
- Beef cows are defined as cows that are not milked. This is true if her milk yield is not registered or the farmer states that all cows are used for beef production.

## 5.2.4 General data

There are three levels of detail: Farm, Livestock category and Individual.

### 5.2.4.1 The farm

Input data from “*Min gård*” (a system provided by Växa) and/or CDB (the central register of bovine animals, administrated by the Swedish Board of Agriculture) is used to determine if there were cows, heifers and/or male cattle on the farm during the period assessed. But this data is not sufficient to determine if the cows are used for milk or beef production or if males are intact or castrated. Hence, the farmer should answer the following general questions:

- Are cows used for milk production?
- Are cows used for beef production?
- Do you raise bulls?
- Do you raise steers?

In addition, the following general data is provided by the farmer

- Organic or conventional production
- Manure storage. Describes how the manure is stored, e.g. coverage of slurry manure.

The Agrosfär model needs data on the feeds used during the period assessed. This data can be provided from different sources, for example from the feed supplier or from the farmer.

Eventually, additional data is needed regarding pasture, for example area (hectare), type of pasture (e.g. cropland, grassland) and quality of the pasture. This information is not collected for the MVP.

#### 5.2.4.2 Livestock category

The following data is provided by the farmer. Data is provided per livestock category that exist on the farm.

- Housing system. Number of heads per system (e.g. deep bedding, tied up & slurry)
- Grazing:
  - Start and end of grazing period (date).
  - Dairy cows - Grazing hours per day. The duration is assumed to be 24 hours per day for any other grazing cattle category.
  - Number of grazing periods for growing bulls. As default, all cattle older than 6 months are assumed to graze during the grazing period, as stipulated by the law. However, bulls are exempt from these requirements. Hence, the farmer has to provide this information
- Feeding regime: Amount of concentrate (kg per year) per livestock category. Distribution of roughage between livestock categories.

#### 5.2.4.3 Individual

Ready input data is/will be available from “*Min gård*” (a system provided by Växa) and CDB (the central register of bovine animals, administrated by the Swedish Board of Agriculture). Eventually, further data sources can be added, for example regarding data related to slaughter.

The following data is collected or could become available per head.

- Breed
- Sex (female/male)
- Date of birth
- Weight at birth (kg)
- Registered weight(s): Date and weight (kg live weight)
- Arrival at the farm: Date and cause (e.g. birth, bought)
- Leaving the farm: Date and cause (e.g. slaughter, sold, death)
- Weight at slaughter (kg carcass weight)
- Cows and heifers: Date of insemination, calving
- Dairy cows: Milk yield (kg per day)

#### 5.2.5 Transition between animal subcategories

Stable systems and feeding regimes can differ between heifers (e.g. manure handled as deep bedding) and cows (manure handled as slurry). The emission calculations are dependent on stable systems and feeding regimes, and hence the transition must be considered.

(Replacement) heifers are categorised as “Heifers” until the day before they give birth. Thereafter, they are categorised as “dairy cows” or “beef cows”. However, in practice, replacement heifers will join the dairy cows some time before calving, and thus the distinction between heifers and cows will not be fully right considering feed and manure

system. It is practical to have the shift at calving day, as this day is known and registered. Furthermore, the small over-estimate of manure in the heifer system and the likewise small under-estimate in the cow system will not make any substantial difference in emissions. There is also a process where heifers are getting used to dairy cow feed before calving, which is not accounted for with this distinction, however in relation to total feed use this simplification should be insignificant.

Castrated males are categorised as steers their entire lives, although they are born as bulls. These males are assumed to be castrated at such young age that potential differences in growth, energy requirement etc. between intact and castrated young males are considered to be insignificant.

## 5.3 Energy requirements

Methane emissions from enteric fermentation and N and VS excretion rates are correlated to animal feed intake. However, detailed and accurate data on actual feed consumption may not be available in cattle production (especially for beef cows) or for the entire year, e.g. during the grazing period. Many dairy farms have good data on the quality (energy and protein content etc.) and consumption of concentrates (kg per cow and day), whereas the quality and consumption of roughage (silage) is not as well known. In addition, there can be good data on feed consumption for the (lactating) cows whereas the farmers don't plan or track feeds to heifers as detailed. Although the amount of roughage fed (kg wet weight) can be known, we would also need reliable data on feed quality (%DM, MJ, crude protein etc.) which is less likely.

Since we can't expect that we'll get consistent data (time and quality) on actual feed consumption, we need to estimate the energy requirement (MJ per head per day). Estimations of energy requirement instead of actual feed consumption is common practice in LCA of beef and milk.

There are several methods/systems available to estimate feed requirement and/or that are used to calculate emissions from enteric fermentation and manure management:

- **NorFor**/The Nordic feed evaluation system (Volden, 2011): Developed for the Nordic countries and implemented in advisory tools such as IndividRAM. IndividRAM will eventually be replaced by FoderOpti. Parts of FoderOpti has been launched, but all functions are not yet available. The Norfor system is used by Växa and Skånesemin.
- Recommendations in **SLU feed tables** (Spörndly, 2003): Not as complex as Norfor. These recommendations have been widely used but have been replaced by the Norfor system in some major applications. The SLU feed tables are still used for example to estimate energy requirements in Swedish NIR and some advisory tools that aren't based on the Norfor system.
- **IPCC guidelines**. Tier 2. The energy requirement is estimated as net energy. The equations are similar to the Norfor system, but not as complex. A great difference is that the IPCC method is developed to assess the average energy

requirement per average head and year, whereas the Norfor system per individual per day.

Energy requirements and the energy content (MJ) of feed can be expressed in different units, see Table 5. All four units are used, or have been used, to express the energy content of cattle feed and/or to calculate methane from enteric fermentation. The energy unit applied should be indicated by “MJ” followed by an abbreviation, for example MJ ME to denote energy content expressed as metabolizable energy. However, other abbreviations can be found in texts in Swedish. For example, “*omsättbar energi*” (i.e. metabolizable energy) can be denoted “OE” or “ME” in texts in Swedish.

MJ ME (*MJ OE*) has long been used in Sweden to express energy content in feed for cattle, e.g. in SLU feed tables (Spörndly, 2003). MJ OE is still in use, for example in advisory tools based on Spörndly (2003), and MJ OE per kg feed can be found in feed analyses. Net energy is used in the NorFor system for estimations of energy requirement and feed evaluation.

Table 5. Energy units to express the energy content (MJ) of feed. The examples of default values and application (current/former) relates to feed for cattle. (Bertilsson, 2016)

Energy unit	What	Where is/was it used?
Gross energy (MJ GE) / <i>Bruttoenergi</i> (MJ GE or MJ BE)	Energy released in total combustion with oxygen. Default value 18.45 MJ/kg DM feed, if own value is not available (IPCC)	Enteric fermentation in IPCCs guidelines and Norfor.
Digestible energy (MJ DE) / <i>Smältbar energi</i> (MJ DE or MJ SE)	GE minus faecal energy. Default: DE = 45% (e.g. poor feeds as straw) to 85% (e.g. high quality feed as grains) of GE	Previous calculations of methane from enteric fermentation, Sweden.
Metabolizable energy (MJ ME)/ <i>Omsättbar energi</i> (MJ OE or MJ ME)	DE minus urinary energy and methane energy. Default: ME = ca 82% of DE	Older feed evaluation system in Sweden (Spörndly, 2003). Current Swedish NIR.
Net energy (MJ NE)/ <i>Nettoenergi</i> (MJ NE)	ME minus heat loss. NE = ca 60% of ME	Newer feed evaluation system (Norfor) in Sweden. Energy requirement in IPCC guidelines

### Assumptions:

- The Agrosfär model can't rely on access to ready data on feed consumption. Hence, energy requirements must be estimated.
- Energy requirements are estimated based on the Norfor system, and the Energy requirements are calculated as MJ NE per head per day.
- Feed intake is assumed to be equivalent to the estimated energy requirements. In practice, feed intake can exceed estimated requirements. This assumption seems to be in line with IPCC guideline.

- Feed intake is estimated based on energy content (MJ NE) in the feed, referred to as the Norfor method. If MJ NE in the feed is not known, but the digestibility is known, then feed intake is estimated based on feed digestibility (DE%), referred to as the IPCC method.

The following sections give a brief description on the estimation of energy requirements of cows and growing cattle, respectively.

## 5.3.1 Dairy and beef cows

### 5.3.1.1 Weight and weight gain, kg

Data on weight and weight gain is needed to calculate energy requirements. It is assumed that average data on body weight of mature animals and default weight gain in young cows is appropriate and sufficient to estimate body weight of a single cow of a single day.

The following assumptions are made regarding body weight of mature cows:

- Refers to the weight of cows that gave birth for the first time more than 730 days ago (older cows).
- The Agrosfär model determine the mature body weight annually as average per breed kept on the farm (kg live weight per head of breed i). The following hierarchy is applied:
  1. Slaughter data (kg carcass weight per head of breed i) for older cows. 1 kg carcass weight is assumed to correspond to 2 kg live weight
  2. Default values from Norfor (Norfor, 2022).

The following assumptions are made regarding weight gain:

- Young cows (1<sup>st</sup> and 2<sup>nd</sup> lactation) gain weight, approximately 50 kg per year (Åkerlind, M. personal communication). Hence, weight gain in young cows is assumed to be 50/365 kg per day from the first day she calves and the following 730 days.
- No weight gain in older cows (i.e. more than 730 days since she calved the first time).
- Fluctuation in weight during lactation is not considered.

### 5.3.1.2 Energy requirement, NEL

The energy requirement is estimated based on the Norfor system (Volden, 2011). Total energy requirement for **cows**, **NEL** (MJ NE per head and day), is calculated as:

$$NEL = NEL_{maint} + NEL_{gest} + NEL_{gain} + NEL_{milk}$$

Where:

$NEL_{maint}$  = Energy requirement for maintenance, MJ NE per cow and day.  $NEL_{maint}$  is calculated as a function of current body weight (see above) and activity. The heavier the animal, the higher the  $NEL_{maint}$ . The more active the animal, the

higher the NEL\_maint. NEL\_maint is assumed to be 10% higher for during grazing ad for loose animals than for animals thar are tied up. This is in line with the Norfor system.

*NEL\_gest* = Energy requirement for pregnancy, MJ NE per cow and day. *NEL\_gest* is calculated as a function of mature body weight (see above) and day in gestation. The higher the mature body weight, the higher the *NEL\_gest*. *NEL\_gest* is low in early gestation and increases gradually the last months in gestation.

Day in gestation is determined based on date of last insemination or date of calving. *NEL\_gest* is only calculated for pregnancies that gives fully developed calf/calves.

*NEL\_gain* = Energy requirement for weight gain, MJ NE per cow and day. *NEL\_gain* is calculated as a function of current body weight and weight gain (see above). The higher the weight gain, the higher the *NEL\_gain*. *NEL\_gain* is included for cows in 1<sup>st</sup> and 2<sup>nd</sup> lactation. Older cows are assumed not to gain weight.

*NEL\_milk* = Energy requirement for milk production, MJ NE per cow and day. Estimated as a function of daily milk yield (kg energy corrected milk, ECM). The higher the milk yield, the higher the *NEL\_milk*. The function is linear. Hence, the annual energy requirement for milk production (MJ NE per year) will be the same regardless of the milk yield per year is expressed as an average for the herd or as individual daily milk yield.

**Dairy cows:** The following hierarchy is used to identify the milk yield of dairy cows:

- i) Measured milk yield (kg milk or kg ECM) per cow per day.
- ii) Measured milk yield (kg milk or kg ECM) per cow per year,
- iii) Milk (kg ECM) delivered to dairies. Corrections are made to consider on-farm consumption of milk (for calves etc.).

If the milk yield is expressed as kg milk, then kg ECM is estimated based on fat and protein content of the milk (measured or default values).

**Beef cows:** The milk yield of beef cows is not measured by farmers. The milk yield is assumed to be 2 000 kg per lactation for any beef cow (Bertilsson, 2016). This is seen as an acceptable generalisation; *NEL\_milk* contributes to a minor share of NEL.

The energy requirement of cows is also affected by mobilisation and deposition. Mobilisation refers to loss of body tissue when the cow is fed under her energy requirements (negative energy balance). Deposition refers to gain of body tissue when the cow is fed over her energy requirements (positive energy balance). Typically, the energy balance is negative in early lactation and should be positive for a short period in mid lactation.

Mobilisation and deposition are not accounted for in the Agrosfär model since the carbon footprint shall represent an annual average. On an annual basis, the energy supply from mobilisation in early lactation is assumed to be balanced by the deposition in mid lactation (Åkerlind, pers comm. 2021).



## 5.3.2 Growing cattle

### 5.3.2.1 Weight and Weight gain, kg

Data on current weight (kg live weight) and weight gain (kg live weight per day) is needed to calculate energy requirements. Typically, the animals are rarely weighted, and current weight and weight gain must be estimated based on (expected) weights at other dates. The following data is required:

1. Weight at birth: Default values from Norfor (Norfor, 2022). Default value is dependent on breed and sex (heifer, bull). This is seen as an appropriate assumption since there are small differences ( $\pm 7$  kg) between breeds.
2. Weight as mature:
  - Heifers: The same assumptions as for cows, see above
  - Bulls and steers: Default values from Norfor (Norfor, 2022). Default value is dependent on breed and sex (bulls, steer).
3. Weight (kg live weight) and age at least at one intermediate date: For example, at the end of the feeding period, when the animal is sold, or from weighing carried out during the feeding period:
  - Heifers: Weight and age at first calving. The weight is assumed to equal the mature body weight of cows of the same breed minus 100 kg. These assumptions are made to correlate the weight and weight gain of heifers with the weight of cows.
  - Bulls and steers: The following hierarchy is applied per individual:
    1. Data from weighing carried out during the rearing period.
    2. Slaughter data for the individual (age at slaughter and carcass weight). 1 kg carcass weight is assumed to equal 2 kg live weight
    3. Average (for the farm) slaughter weight and age at slaughter for the category (bull/steer) and breed raised at the farm. 1 kg carcass weight is assumed to equal 2 kg live weight
    4. Estimated based on default age at slaughter and body weight of mature males (breed-specific).

Current weight and weight gain is estimated as in Norfor (Volden, 2011).

### 5.3.2.2 Energy requirement, NEG

The same equations are used to estimate energy requirement of both dairy breed and beef breeds, and for heifers, bulls and steers.

The net energy requirement, NEG (MJ NE per growing cattle and day), for growing cattle is estimated per head and day as:

$$NEG = NEG_{maint} + NEL_{gain} + NEL_{gest}$$

Where:

$NEG_{maint}$  = Energy requirement for maintenance, MJ NE per growing cattle and day.  $NEG_{maint}$  is calculated as a function of current body weight (see above) and activity. The heavier the animal, the higher the  $NEG_{maint}$ . The more active the animal, the

higher the *NEG\_maint*. *NEG\_maint* is assumed to be 10% higher for during grazing ad for loose animals than for animals thar are tied up (Åkerlind, personal communication).

*NEG\_maint* is also dependent on sex and breed. At a given weight, *NEG\_maint* is higher for bulls than for heifers and steers. In addition, *NEG\_maint* is higher for bulls of beef breeds than of diary or crossbreeds.

*NEL\_gain* = Energy requirement for weight gain, MJ NE per growing cattle and day. *NEL\_gain* is based on several sub-equation that estimate daily protein retention in the animal (g protein/day), daily fat retention (g/day), the efficiency of ME for maintenance and growth, and the utilisation coefficient of ME to NE for growth.

One of the parameters is the ratio “Metabolizable Energy/Gross Energy” of the feed ration. It is assumed that the ME/GE ratio is 60% for any feed ration. This is a common ratio applicable for feed rations (Åkerlind pers comm, 2021). Individual feeds and ingredients have higher or lower ME content. Some concentrates, protein feeds, cereals etc. have higher ME content (up to circa 90% of GE), roughage ca 55-62% ME of GE, and straw and bran the lowest (<50%).

*NEL\_gest* = Energy requirement for pregnancy, MJ NE per heifer and day. Same as for cows, see above.

## 5.4 Feed characteristics

A nutrient profile of feeds is required to estimate feed intake (dry matter intake, DMI) and emissions from enteric fermentation and manure management. Data can be derived from feed analyses and databases, for example feedstuff tables from Norfor or SLU<sup>2</sup>. However, the datasets may not be complete and contain all parameters required for the Agrosfär model. Many farmers analyse the nutrient content, for example energy and protein content, of crops grown on the farm, but other parameters that are required in the Agrosfär model may not be included in the analyses or known by the farmer.

In addition, there are various methods to analyse the feed and the results from different methods may not be comparable. The energy content of feeds is expressed as net energy in Norfor’s feedstuff table, whereas the energy content is expressed as metabolizable energy in SLU’s feedstuff table.

Hence, two pathways have been described to characterise the feeds and to estimate DMI. The first and preferred pathway is called the **Norfor method**, which presumes that the net energy content of all feeds is known. The second pathway is called the **IPCC method**. The IPCC method is used if net energy content of the feed is unknown. The IPCC method requires that the digestibility (DE) of the feed is known, which can be found in some feed analyses and SLU’s feedstuff table.

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<sup>2</sup> <https://www.slu.se/institutioner/husdjurens-utfodring-var/Verktyg/>

### 5.4.1 Feed characteristics

If the **Norfor** method is applied to estimate DMI, the following parameters are needed per feed:

- Dry matter content, DM [%]
- Particle size, PS [mm], or type of feed (concentrate or roughage)
- Ash content or Organic matter content, OM [g/kg DM]
- Apparent total digestibility of organic matter OMD. OMD can be expressed as OMD, OMD<sub>20</sub>\* and/or OMD<sub>8</sub>\* [% of OM]
- Crude protein (CP) or Ammonia- or urea corrected crude protein (CP<sub>corr</sub>) and Ammonia and urea content (NH<sub>3</sub>N) [g/kg DM]
- Crude fat (CFat) and fatty acids (FA) [g/kg DM]
- Net energy, NEL<sub>20</sub>\* and/or NEL<sub>8</sub>\* [MJ NE/kg DM]
- Carbon footprint of the feed [g CO<sub>2</sub>-eq./kg DM or kg]

\* "20" and "8" represents the feed value at 20 kg DMI and 8 kg DMI, respectively. See section 5.5.1.1.

If the **IPCC** method is applied to estimate DMI, the following parameters are needed per feed (see section 5.5.1.2 for more details):

- Dry matter content, DM [%]
- Particle size, PS [mm], or type of feed (concentrate or roughage)
- Ash content or Organic matter content, OM. [g/kg DM]
- Digestibility or digestible energy [% of OM or MJ/kg DM]
- Crude protein (CP) [g/kg DM]
- Crude fat (CFat) [g/kg DM]
- Metabolizable energy [MJ ME/kg DM]
- Carbon footprint of the feed. [g CO<sub>2</sub>-eq./kg DM or kg]

### 5.4.2 Definition of feed categories

The Agrosfär model needs to identify what category of feed each feedstuff belongs to. "Type of feed" is needed in the calculation of methane from enteric fermentation and can be used to set default values on nutrient content of feeds.

All feeds are categorised in one of two main categories: i) Roughage and ii) Concentrates. Norfor distinguishes between Roughage and Concentrate based on particle size, PS (mm). Feedstuff with particle lengths >6 mm is defined as Roughage, feedstuff with particle length ≤ 6 mm as Concentrate (Volden, 2011). PS is given for all feeds in the Norfor table.

**Concentrates** include for example concentrates, grain, distillers' grain, oil seeds, peas, soy, minerals, and milk powder fed to calves. In the Agrosfär model, concentrates are further divided into the following three subcategories:

- a) Concentrates\*: Any concentrate that is not identified as one of the subcategories below

- b) Milk substitutes: Fed only to calves
- c) Minerals: minerals, vitamins. No or very low content of organic matter.

It is assumed that:

- The amounts of any concentrates fed to the animals is known to the farmer, or at least that the farmer can estimate the amount of concentrates fed.
- The farmer can provide information on how concentrates\* are distributed between dairy cows, beef cows and growing cattle, respectively.
- Feeds that are identified as Milk substitutes can only be fed to calves.
- Feeds that are identified as Minerals don't have to be distributed between animal subcategories. They are fed in very small amounts and contain no or little organic matter. Hence, it is assumed that minerals can be excluded without any effect on emission calculations.
- The quality (e.g. DM, MJ, crude protein) of concentrates\* is known

**Roughage** includes for example ley crops (grass, clover-grass, alfa-alfa etc.), maize crops aimed for silage and fodder beets. In the Agrosfär model, roughage is further divided into the following subcategories:

- a) Harvested roughage: Roughage that is harvested and thereafter fed to animals.  
E.g. silage and hay
- b) Pasture: Roughage that is grazed directly by the animals.

It is assumed that:

- The amount of harvested roughage fed to the animals is not known in great details. The farmer can provide information on how harvested roughage is roughly distributed between dairy cows, beef cows and growing cattle, respectively. Hence, the Agrosfär model will estimate the amount of roughage consumed based on the energy requirements of the animals and the energy provided from concentrates.
- The energy and protein content of harvested roughage can be known by the farmer, but other quality parameters (e.g. ash, crude fat) has to be provided by the Agrosfär model.
- The amount of pasture (kg DM per head and day) or the yield (kg DM per hectare and year) is not known by the farmer. The Agrosfär model estimates the amount of pasture consumed based on energy requirements during the grazing period.
- The feed value of pasture is not known in great details and must be estimated indirectly. For the MVP, the quality of the pasture is assumed to equal the quality of harvested roughage fed to the animals.

## 5.5 Estimation of dry matter intake – kg DM roughage unknown

Given that the DMI of roughage (silage, hay and other harvested crops) is unknown, the daily feed intake (dry matter intake, DMI, kg DM per day) is estimated based on net energy requirements.

DMI can be estimated in two ways depending on the feed evaluation system applied.

- Norfor method: Based on Net energy. The net energy content of feeds must be provided (NEL20 and/or NEL8). Suggested as the first-hand option.
- IPCC method: Energy requirements are estimated as net energy, but the feed digestibility is used to estimate feed intake. The digestibility of the feed must be provided. Suggested as an alternative for farmers that don't have access to the Norfor system or when the net energy content of the feed ration is unknown.

The energy balance, that is the energy supplied from the feed ration divided by the total energy requirement, is assumed to be 100% on average per animal and year. Ideally, the energy balance should be 100%. However, the animals can consume more (or less) feeds, which results in a higher (or lower) energy balance. In the long run, the animals will gain more fat if the energy balance is higher than 100%.

Note that the amount of feed given to the animals can exceed the amount of feed consumed by the animals. Some feeds can be left uneaten, see section 5.9.3. Uneaten feed is not included in the estimations of emissions from enteric fermentation and manure management. The fate of uneaten feed can be included later.

### 5.5.1 Estimate energy content of feeds

#### 5.5.1.1 Norfor method

The net energy supply from feeds (MJ per kg DM) depends on several parameters, for example dry matter intake (DMI). High feed intake implies faster passage of the feeds through the rumen and intestines, and lower utilisation efficiency of the energy content of the feeds. Hence, a lactating dairy cow with high DMI will utilise less of the energy content of the feeds than a dry cow that eats less.

The Norfor system accounts for this aspect and estimates the net energy value for a feed ration based on, for instance, DMI. These estimations are refined, and too detailed to be implemented in the Agrosfär model. However, standard feed values on net energy content of feeds can be found in feed analyses and the Norfor feed table. These standard feed values are given for two levels of DMI, that is 20 kg DMI (NEL20) and 8 kg DMI (NEL8). The NEL8 value of a feed is higher than the NEL20 value. – sdg

It is assumed that NEL20 and NEL8 of feeds can be used as an approximation for the net energy supply from the feed ration. The Norfor feed table contains NEL20 and/or NEL8

for many feeds, whereas the net energy content is usually expressed as NEL20 in feed analyses and data from feed suppliers.

### 5.5.1.2 IPCC method

The IPCC method presumes that the gross energy content (MJ GE per kg DM) and digestibility of feeds is known.

The gross energy content of feeds is estimated based on their content of fat, proteins, and carbohydrates. These parameters can mostly be found in feed tables and feed analyses. Alternatives are default values, e.g. 20 g crude fat per kg DM roughage, or recalculation. The content of carbohydrates can be estimated as: Organic matter (g/kg DM) – Crude protein (g/kg DM) – Crude fat (g/kg DM)

Digestibility of feed can be expressed in different units. The unit is DE% (MJ DE per MJ GE) in the IPCC guidelines. Digestibility is expressed as % of OM (concentrates) or as MJ DE per kg DM (roughage) in the feed table from SLU (Spörndly, 2003). The digestibility of roughage can be recalculated to DE% if the gross energy content is known, which is similar to the units applied in the IPCC guidelines. It seems as if the digestibility expressed as DE% and % of OM is quite similar.

The digestibility of feeds is given in the Norfor table as well. However, these values do not seem to correlate to DE% as expressed in the IPCC guidelines.

If the IPCC method is used, the following hierarchy is applied to select the digestibility of feed:

1. Feed-specific data on digestibility, expressed as MJ DE per kg DM.
2. Feed-specific data on digestibility, expressed as % of OM.
3. Default value

### 5.5.2 DMI - kg feed consumed

We need to know the amount of feed consumed by the animals (kg DM per feed and per day). The total feed intake (DMI, kg DM per animal and day) must be known as it is used to calculate methane emissions from enteric fermentation, both from cows and growing cattle. We also need data on average feed characteristics (fatty acids, NDF and ash) and the proportion of concentrates in the feed ration for growing cattle.

The feed ration is not constant or similar for all animals. The feed ration varies during the year, there are for example differences between the grazing period (up to 100% of energy supply from pasture) and the winter/stable period. Lactating cows are fed much more concentrates than dry cows. The feed ration varies as the growing cattle gets older.

The data quality and availability vary regarding the amount of feed fed to the animals. The amount and feed values of concentrate is generally recorded, and the farmer knows if the concentrates are given to cows and/or growing cattle. On the other hand, the quality and yield (kg DM per hectare) of pasture is not known as detailed.

The following assumptions are made regarding **concentrates**:

- The amount of every concentrate fed to cattle is known, i.e. kg concentrate<sub>i</sub> per year fed to dairy cows, beef cows and growing cattle, respectively.
- Dairy cows:
  - Concentrates allocated to dairy cows is assumed to be given to lactating cows. Hence, dry cows do not eat any concentrates.
  - Lactating cows are fed concentrates all year around.
  - The concentrates are distributed between lactating cows proportional to their energy requirement.
- Growing cattle and beef cows:
  - Growing cattle and beef cows are fed concentrates during the stable period.
  - The concentrates are distributed between growing cattle proportional to their energy requirement.
  - The concentrates are distributed between beef cows proportional to their energy requirement.

The following assumptions are made regarding **pasture**:

- The grazing period is record separately for the categories lactating dairy cows, dry cows, beef cows, bulls, and heifers/steers
- For the MVP, the feed value of pasture is assumed to equal the feed value of harvested roughage fed to each category.
- The farmer provide data on the grazing period regarding length of the grazing period (start and end date, every categories), duration (hours per day, dairy cows) and number of grazing seasons (bulls).
- Beef cows, bulls, and heifers/steers:
  - The duration is assumed to be 24 h/day.
  - They only consume roughage (pasture, and potentially additional harvested roughage) during the grazing period.
- Dairy cows:
  - The energy supply (MJ) from pasture is assumed to be proportional to the duration. If the cows graze 6 hours per day, then pasture constitutes  $6/24 = 25\%$  of her energy supply.

The following assumptions are made regarding **harvested roughage**:

- The farmer can roughly estimate the amount of harvested roughage fed to cattle, and roughly distribute the amount between dairy cows, beef cows and growing cattle.
- The amount consumed is estimated as the difference between calculated energy requirement and energy supplied from concentrates and pasture.  
Example: If the energy requirement of a lactating dairy cow is 150 MJ NEL per day and the energy supplied from concentrates correspond to 55 % of her energy requirements, then harvested roughage =  $150 \text{ MJ NEL} \cdot (1 - 55 \%) = 67.5 \text{ MJ NEL}$ . If the energy content of harvested roughage is 6.1 MJ NEL<sub>20</sub>/kg DM →  $67.5/6.1 = 11.1 \text{ kg DM}$  harvested roughage per day.

Comments regarding **young calves**: Young calves (pre-weaning) do not emit (or emit small amounts of) methane from the rumen (Gavrilova et al., 2019). The IPCC guideline suggests that the methane conversion rate is zero for juveniles consuming only milk, which implies zero methane emissions from enteric fermentation of juveniles. In the Swedish NIR, the pre-weaning period is assumed to be two months for calves of dairy breeds and three months for calves of beef breeds.

These assumptions implemented in the Agrosfär model by excluding the energy requirement of calves pre-weaning. Hence, we don't need to consider and distribute energy supply from milk substitutes intended for calves pre-weaning. However, this simplification implies that N and VS excreted pre-weaning is excluded and that the excretion rates of growing cattle is underestimated. The excretion rates are determined from the feed intake, and the feed intake is determined from the energy requirement, and the energy requirement of young calves is excluded in NEG. However, N and VS excreted by calves is assumed to be negligible compared to the excretion rates and number of older animals.

It is weaning age is assumed to be 2 months for calves of dairy breeds and 3 months for calves of beef breeds (Naturvårdsverket, 2021a).

## 5.6 Enteric fermentation

Methane from enteric fermentation is estimated as in Swedish NIR (Bertilsson, 2016; Naturvårdsverket, 2021a). There are separate equations for cows and growing cattle. The emissions are estimated per head and day.

Methane from **cows** is estimated based on dry matter intake (DMI) and the concentration of fatty acids in the feed ration. The higher the DMI, the higher the methane emissions. The higher the fatty acid content, the lower the methane emissions. The same equation is used for dairy and beef cows.

Methane from growing cattle is estimated based on the feed intake and proportion of concentrates in the feed ration (% of DM). The feed intake is expressed as gross energy, MJ GE per head and day. The higher the gross energy intake, the higher the methane emissions. The more concentrates in the feed ration, the lower the methane emissions.

Note that the energy requirements and methane emissions from calves pre-weaning are not included. The pre-weaning period is assumed to be two months for calves of dairy breeds and three months for calves of beef breeds.

## 5.7 Manure management

This section covers emissions from the stable (NH<sub>3</sub>), storage of manure (NH<sub>3</sub>, N<sub>2</sub>O and CH<sub>4</sub>) and manure deposited on pasture (NH<sub>3</sub>, N<sub>2</sub>O and CH<sub>4</sub>), see Figure 2. Emissions



from manure management depends on housing and manure management systems, and on the amount of N and VS (volatile solids) excreted by the animals. Major housing and manure management systems are included. However, treatment of manure, e.g. anaerobic digestion, separation of slurry or acidification of slurry, is not yet included.

In the Agrosfär model, emissions of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  from manure dropped outdoors on pasture and range are included in manure management. This is a difference from the IPCC guideline in which  $\text{CH}_4$  is reported as emissions from Manure Management whereas  $\text{N}_2\text{O}$  is reported as soil emissions. However, the crop production module in the Agrosfär model does not cover soil  $\text{N}_2\text{O}$  emissions induced by manure deposited on pasture by grazing animals.

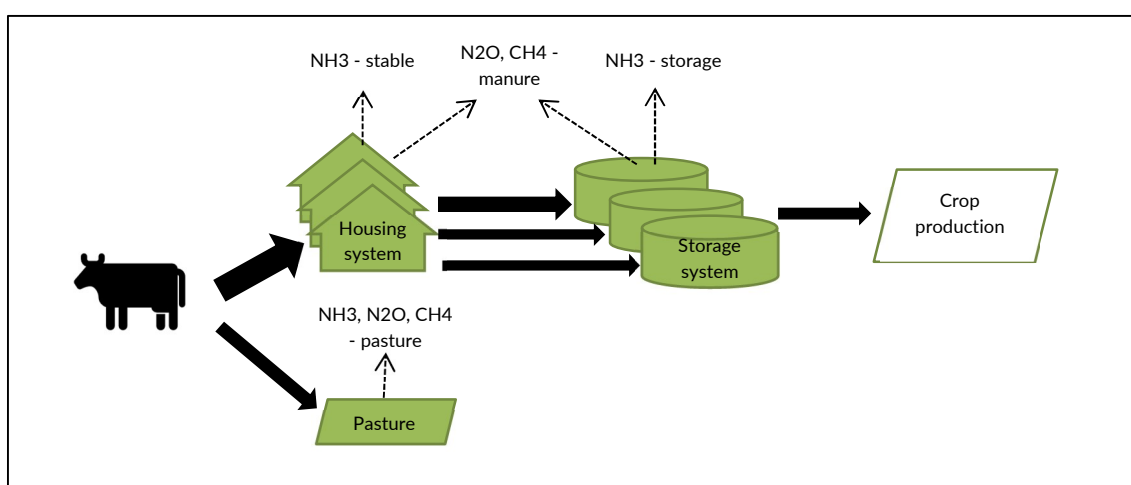


Figure 2. Illustration of flows of manure (black arrows) between compartments (green areas), and emissions from the manure management system (dotted arrows). Emissions from spreading of manure is described in the section on crop production.

### 5.7.1 Housing system and manure storage system,

Emission rates depend on the housing system and the manure storage system(s) on the farm, and the distribution of manure between systems.

The following data is provided by the farmer:

- For each animal category: The number of heads per housing system and corresponding type of manure, for example loose & slurry, loose & deep bedding, or tied up & solid manure. The animal categories are dairy cows, beef cows, heifers, bulls, and steers.
- Coverage of manure storages: The share (%) of slurry and urine stored with and without cover (crust or coverage).

#### Comments on housing systems:

The aggregation and disaggregation of animal categories (i.e. one category of Dairy cows and three subcategories of Growing cattle, respectively) aims to facilitate data collection.

These categories and structure (heads per manure management system) should be known by the farmer and are similar to the categories applied in VERA.

During the grazing period, VS and N excreted is allocated to pasture proportional to the duration of grazing (h/day). Some cattle can go outdoor during the stable period. However, manure dropped outdoors during the stable period is not accounted for.

Some housing systems generate two types of manure. An example is systems where manure is separated in the stable into a solid fraction ("solid manure") and a liquid fraction ("urine"), and the fractions are stored separately. In this case, N and VS excreted indoors is automatically distributed between the solid and liquid fraction dependent on fate of faeces and urine deposited by the animals. It is assumed that 100% of the faeces and 25% of the urine ends up in the solid fraction, and 75% of the urine in the liquid fraction. It is assumed that 100% of VS is excreted as faeces, and that 50% of N is excreted as faeces and 50% as urine. This is the same distribution as the general assumption in the IPCC guidelines, chapter 10.5.2 (Gavrilova et al., 2019).

The N and VS excreted indoors is allocated between housing systems proportional to the fraction of each animal category assigned to the system. Hence, the proportion between different types of manure (slurry, solid, deep bedding, and urine) produced per animal category will be the same although the number of animals may vary over the year or differ from the information given by the farmer. Example: If the farmer says that there are 40 heifers on deep bedding and 60 heifers loose on slurry, then 40% of N and VS excreted will be handled as deep bedding and 60% as slurry, regardless of the number of heifers on the farm and the age of the heifers.

This approach may give a skew distribution between manure systems for instance if young calves are housed on deep bedding whereas the manure from older heifers is handled as slurry. However, it is assumed that the proportional distribution of manure is suitable and sufficient for the Agrosfär model and reduces the risk of errors in data collection.

### **Comments on manure storage systems:**

The manure can be handled and stored as slurry, urine, deep bedding, or as solid manure. Emissions rates differ between the types of manure. The following assumptions are made about each type of manure:

- **Slurry:** Emission rates depends on the coverage of the storage. Three alternatives are given: Natural crust, Other cover (e.g. lid), or No cover.
- **Urine:** Emission rates depends on the coverage of the storage and whether urine is stored separately or with slurry. Three alternatives are given: Stored with slurry, With cover (e.g. lid) or Without cover
- **Deep bedding and solid manure:** No differences in emission rates between storage schemes.

## 5.7.2 Methane emissions

Methane from manure management is estimated as a function of VS excretion rates, the maximum methane-producing capacity of the manure ( $B_o$ ) and a Methane Conversion Factor (MCF). The method is similar to the Tier 2 approach in the IPCC guidelines (Gavrilova et al., 2019).

The **VS excretion rate** is estimated based on the Norfor method or the IPCC method, depending on data available regarding digestibility of feeds. The Norfor method is preferred.

The Norfor method: VS excreted is calculated as a function of DMI, ash content in feeds, and total apparently digested organic matter (td\_OM). DMI is estimated in the Agrosfär model, and the ash content is generally known. td\_OM is not known as frequently but can be found for a range of feeds in the Norfor table (td\_OM20 or td\_OM8) or can be estimated as a function of the apparent total digestibility of organic matter.

The IPCC method: the VS excretion is estimated as a function of gross energy intake, digestibility of the feed ration and energy lost via urine.

The maximum methane-producing capacity of the manure,  $B_o$ , is expressed as default values. The  $B_o$  values comes from the IPCC guidelines and refers to cattle in Western Europe (Gavrilova et al., 2019).  $B_o$  for manure from dairy cow is higher (0.24 m<sup>3</sup> CH<sub>4</sub> per kg VS) than for manure from other cattle (0.18 m<sup>3</sup> CH<sub>4</sub> per kg VS). Dairy cows have high feed intake which implies lower utilisation efficiency of the energy content of the feeds and that more easily degraded organic compounds remain in the manure.

More specific  $B_o$  values are preferred but are not yet available.

**MCF** describes the amount of methane produced in relation to  $B_o$ , and it is expressed as % of  $B_o$ . The MCF depends on the manure management system. Methane is produced under anaerobic conditions (no oxygen available), and the methane production rate depends on the temperature. The following national adopted MCFs are applied (Naturvårdsverket, 2021a):

- Slurry and urine: 3.5 %. Low MCF although the environment in slurry and urine is anaerobic. Frequent removal of manure from the stables and low ambient temperature contributes to low methane emissions under Swedish conditions.
- Deep bedding: 17%. Higher MCF due to the composting process that produce heat and consumes oxygen, which can imply partial anaerobic conditions.
- Solid manure: 2%. Low MCF due to aerobic conditions.
- Manure dropped on pasture: 1%. Low MCF due to aerobic conditions.

## 5.7.3 Direct nitrous oxide emissions

Direct N<sub>2</sub>O emissions, dN<sub>2</sub>O, from storage of manure is estimated as a function of N excretion rate and emission factors. The calculations are based on the IPCC method. The

Norfor method can be used to estimate N excretion rate, but there is no information on how N<sub>2</sub>O emissions are estimated in the Norfor system.

Direct N<sub>2</sub>O emissions is estimated as a function of an emission factor and the amount of N excreted by the animals. The amount of N should reflect the amount on N prior to losses of ammonia.

The **emission factor** describes the share of N excreted that is converted and emitted as N<sub>2</sub>O (kg N<sub>2</sub>O-N per kg N excreted). The emission factor depends on the manure management system. The following national adopted emission factors are applied (Naturvårdsverket, 2021a):

- Slurry, urine and solid manure: 0.005 kg N<sub>2</sub>O-N per kg N
- Deep bedding: 0.01 kg N<sub>2</sub>O-N per kg N
- Manure dropped on pasture: 0.02 kg N<sub>2</sub>O-N per kg N

The total amount of **N excreted** in urine and faeces estimated based on the Norfor method (Volden, 2011). N excreted is the difference between intake of N and retention of N in body tissue (foetus and weight gain) and milk (protein content in milk). Intake of N is estimated based on DMI and protein content of the feed ration.

There are equations in Volden (2011) on how to separately report N excreted in faeces and N excreted in urine. However, there are many sub-equations and parameters needed on digestion of protein and organic matter. It is concluded that the great effort needed to acquire these separate data are not proportional to the gain of reporting N content separately in the Agrosfär model. Most cattle manure is handled as slurry, and less and less as solid manure or urine. The N<sub>2</sub>O emission factors for Solid manure and Urine are similar, so the exact fate of N excreted is not crucial. In addition, solid manure is “contaminated” by urine, an vice versa.

## 5.7.4 Indirect nitrous oxide emissions

Indirect N<sub>2</sub>O emissions, iN<sub>2</sub>O, from stable and storage of manure is estimated as a function of N excretion rate, N in bedding materials and emission factors that describes ammonia emissions (kg NH<sub>3</sub>-N per kg N in manure, including bedding materials) and conversion of NH<sub>3</sub> to N<sub>2</sub>O. The calculations are based on the IPCC method but supplemented with national emission factors for ammonia.

The **emission factors for ammonia** comes from the Swedish advisory tool VERA supporting materials. These emission factors comprise ammonia emissions from stable and storage of manure, respectively, including N in bedding materials. Hence, N in bedding materials is added when the ammonia emissions are estimated. In addition, the emission factor for storage of manure is expressed as a fraction of N remaining in the manure post NH<sub>3</sub> emissions that occurred previously in the stable.

The amount of **bedding materials** is estimated as default values (kg bedding material per head and day) per housing system and animal category (dairy cows, beef cows, heifers, bulls, steers). Default values comes from VERA. The bedding material is assumed to be straw, and the N content of straw is 0.007 kg N per kg straw.

The **emission factor for indirect N<sub>2</sub>O** comes from the IPCC guidelines. The default aggregated value is applied, that is 0.01 kg N<sub>2</sub>O-N per kg NH<sub>3</sub>-N emitted (Gavrilova et al., 2019).

According to the IPCC guidelines, the estimation of iN<sub>2</sub>O should include N leaching from manure management. However, it is assumed that N leaching from manure management is insignificant and is not included in the Agrosfär model.

## 5.8 Dead cattle

Cattle which die on farm or are slaughtered prematurely and where the meat cannot be sold are included as long as they are alive. Thus feed consumption, enteric fermentation and manure production are calculated up to the death of the animal. The carcass weight is not included in the output from the production, and the burden of the dead animal's life is carried by the total output from the animal production. The waste handling of the carcass was not included in the MVP.

## 5.9 Feed waste and losses

### 5.9.1 Storage losses of silage

Losses of silage during storage are losses due to the silage process and microbial digestion of the matter. These losses are about 1% of DM for round bale silage, while losses are greater, about 20% of DM, for bunker silos, stack silage and tower silos (Abrahamsson, 2012; Spörndly and Nylund, 2017). This loss was not accounted for in the MVP.

### 5.9.2 Unusable feed

Unusable feed is feed which has become unfit for feeding before given to animals, e.g. due to mold. The magnitude of these losses depends partly on the storage method. For round bale silage, losses are usually low, up to 8%, as they do not need to stay open for long due to their small size (Bannbers et al., 2021; Spörndly and Nylund, 2017). For different types of silos, losses appear to be higher, although there are large differences between different studies and also between different farms within the same study, ranging from 0 to 35% (Bannbers et al., 2021; Spörndly and Nylund, 2017). For concentrate feed, we have found no literature covering losses. Losses due to feed being unusable were not included for the MVP. In coming versions, it will be included as a higher feed input needed for the production, however waste management of this feed will not be included in the model.

### 5.9.3 Uneaten feed

Uneaten feed is feed which was given to livestock but left uneaten. Again, we have found no data covering uneaten concentrates, but since this kind of feed is particularly tasty for the animals, we have assumed a low loss rate, 0.5%, for all feeding arrangements. For roughage feed fed indoors, we have assumed 4% losses, based on information from Hessle (2021), Bannbers (2021), Lindström and Gren (2009) and DairyNZ (2017). For outdoor feeding off-ground we assume 10% losses, while for feed given on the ground outdoors we assume 40% to be lost in wet climates/seasons and 20% in dry climates/seasons, based on figures given by DairyNZ (2017). For the MVP, we have used a standard figure of 30% losses of roughage fed outdoors.

## 6 Energy use at farm

Total climate impact from energy use at farm is calculated from measured annual electricity use, fuel consumption and if relevant the use of district heating/cooling.

$$CI_{tot_{energy}} = \sum_l CF_{energy_l} \times EF_{fuel_l} + \sum_m CE_{energy_m} \times EF_{el_m} + \sum_n CE_{heat_n} \times EF_{heat_n}$$

Where:

$CI_{tot_{energy}}$  = Total climate impact used energy, [kg CO<sub>2</sub>-eq.]

$CF_{dry}$  = Measured fuel consumption, [unit/y], unit may vary with fuel type

$EF_{fuel_l}$  = Emission factor of fuel type  $l$ , [kg CO<sub>2</sub>-eq./unit], unit may vary with fuel type

$CE_{dry}$  = Measured electricity consumption, [MWh/y]

$EF_{el_m}$  = Emission factor of electricity source  $m$ , [kg CO<sub>2</sub>-eq./MWh]

$CH_{energy}$  = Measured heat consumption, [MWh/y]

$EF_{heat_n}$  = Emission factor of heat source  $n$ , [kg CO<sub>2</sub>-eq./MWh]

Emission factors for fuel, electricity and district heating are from Energimyndigheten and Energiföretagen.

# 7 Future improvements

In the following section potential improvements of the Agrosfär tool are described. Some improvements are dependent on development of calculation procedures or establishment of scientifically accepted methods; these improvements can be implemented in the long-term. Other improvements can be directly implemented in the tool in a second version.

## 7.1 System boundaries and system scale

### 7.1.1 Total farm GHG emissions

The MVP assesses the climate impact for the farm outputs i.e. carbon footprint per unit of milk, meat or crop. The aim in future versions of the Agrosfär tool is to calculate GHG emissions also for the whole farm enterprise. This will require a deeper analysis of the time perspective. A few examples: Feed produced on-farm may be stored for the next calendar year or even longer, manure may be applied to the soil the year after it was produced, fuel can be bought one year and used the next, and ley crops are not ploughed every year.

With a product perspective, the time-perspective is not relevant; all emissions that belong to that product is included regardless of when they occur. A farm level perspective on the other hand will report the emissions from that farm during one year. Further, there are certain emissions e.g. from fallow land, that are not included in the product perspective, but would be included in the total farm emission. In other words, a farm perspective requires paraphrasing the system boundary for the model.

### 7.1.2 Capital goods, infrastructure, and machinery

Capital goods, infrastructure and machinery is not included in the MVP. The requirement of inclusion according to guidelines varies. ISO and GHG protocols do not require inclusion of capital goods. According to PEFCR capital goods, including infrastructure, can be excluded if their contribution to GHG emissions is less than 1% of total GHG emissions. According to PEFCR dairy capital goods at the dairy unit can be excluded as they generally contribute to more than 1% of total GHG emissions. GFLI includes depreciation of capital goods and machinery needed for practicing cultivation and storage. In future versions of Agrosfär tool capital goods can be included, for e.g by using default emission factors. How and which capital goods to include needs further discussion.

### 7.1.3 Connection between animal and crop model

The animal and crop model will be closer interlinked in future version of the tool. Manure produced in the animal model can be transferred to the crop production, however this requires solving the question regarding addition of water to the manure.



From the crop model actual information on amount feed produced could be matched with the animal model, however this requires of the model to be able to account for feed stock changes between years and keeping track on information about amount of feed being sold from the farm and feed being fed to on farm animals.

Also, energy is used on the farm both in crop and animal production. See more in section 7.6.

### 7.1.4 Uncertainty ranges

In the first version of Agrosfär, uncertainty ranges are not included, e.g. for emission factors used for direct N<sub>2</sub>O emissions. Before including uncertainty ranges it is important to consider what value the inclusion of uncertainty ranges will bring to the user and in that case, what type of uncertainty is most important to communicate to the user of the tool.

## 7.2 Nitrous oxide emissions

N<sub>2</sub>O emissions make up a great part of the crop production GHG emissions, the method for calculating N<sub>2</sub>O emissions is therefore of great importance. At the same time, the N<sub>2</sub>O emissions are one of the most uncertain parts of agricultural climate estimations. Despite these uncertainties, there are a few suggested improvements for the calculations:

### 7.2.1 N<sub>2</sub>O from crop residues

The calculation of nitrogen turnover from crop residues builds on a generic value for the ratio between crop yield to crop residues. The yield to crop residue ratio builds on IPCC 2019 values. For some crops the IPCC ratios are not representative for Swedish production. It was discussed to use values from the Swedish NIR report, which are adopted to Swedish conditions and the list of crops is more extensive than IPCC, however the NIR values overestimate N<sub>2</sub>O emissions for potatoes, sugar beets and tubers. It was therefore decided to use IPCC values.

The ratio between crop yield to crop residue can for some crops be misleading e.g. ley cultivated for ley-seed production, where a much smaller yield is harvested than for ley harvested for silage production. In Agrosfär this is solved by adding a “thought” yield level. It needs to be investigated if this makes a fair representation.

The method for calculation of crop residues is unclear in IPCC for crops where the harvested part is below ground, e.g. sugar beet or potatoes. It is not clear whether the roots and tubers should be treated as below ground biomass or above ground biomass in the calculations, as they are removed from the field and should not contribute to N<sub>2</sub>O emissions from crop residue N turnover in soil. This needs further investigation.

In the current Agrosfär tool values for “grain” are used when calculating N<sub>2</sub>O emissions (above and below ground biomass etc). There is the option to use more disaggregated values per crop e.g. winter wheat, barley etc (table 11.1A, Hergoualc’h et al. (2019)). It

should be investigated how a disaggregation would impact the results and if it is applicable for Swedish production of grains.

Some crop residues have faster turnover than others (e.g. sugar beet tops vs straw) which could influence N<sub>2</sub>O emissions. This is not included in the present model but could be a future improvement as science progresses.

## 7.2.2 Direct N<sub>2</sub>O from soil

Currently the aggregated method for calculating N<sub>2</sub>O emissions from IPCC 2019 is adopted. In the future it could be an option to use disaggregated emission factors, specified for climate type (dry/wet) and fertiliser type. However, the disaggregated emission factors provided in IPCC 2019 are designed from global averages, and there are large uncertainties regarding whether they would provide more accuracy to the model, than using the aggregated values.

In the current model it is not taken into consideration that more N<sub>2</sub>O is released when soil-C is higher, this could be included in a second version of the model given there is enough scientific evidence and available emission factors.

## 7.2.3 Indirect N<sub>2</sub>O emissions from soil

NH<sub>3</sub> emissions contribute to indirect N<sub>2</sub>O emissions. Currently the farmer needs to provide information in the Agrosfär model on timing of spreading manure, which has an impact on NH<sub>3</sub> emissions. As Swedish regulations do not allow for manure to be spread during certain parts of the year for different regions, an alternative method could be to use the location of the farm, as the basis for spreading time of manure. There are also emission factors available for indirect N<sub>2</sub>O emissions (NH<sub>3</sub> emissions) disaggregated by climate zone and fertiliser type, this can be developed in a future version but requires a climate division of the Swedish municipalities.

## 7.2.4 Pasture emissions

Pasture emissions are only partially covered in the Agrosfär model. Indirect N<sub>2</sub>O from N-leaching in pasture is not included. As these grasslands are usually nutrient poor, we can expect these emissions to be very low and are therefore not included in the model, however for completeness these should be added. Further, emissions from more carbon and nutrient rich semi-natural pastures should be included in a later version of the Agrosfär tool.

# 7.3 Emissions from organic soils

Currently N<sub>2</sub>O and CO<sub>2</sub> emissions from organic soils are included by using default emission factors, applied on all soils with an organic matter content > 30%. This is according to PEFCR dairy, however PEFCR feed requires that CO<sub>2</sub> emissions shall be calculated based on a model that relates the drainage levels to annual carbon oxidation. Also, FAO LEAP suggests collecting data on groundwater levels and using emission

factors relating to soils with different groundwater levels. When an appropriate model is available for such an inclusion this can be included in the Agrosfär tool.

Emissions of CO<sub>2</sub> and N<sub>2</sub>O from organic soil pastures are not included. Even though these types of soils are rare, a farm could have the bad luck of having many of these types of soils. However, emission factors have been prepared for pastures on organic soils and this can be included in later versions of the Agrosfär tool.

## 7.4 Animal production model

After the MVP it should be determined which data could be requested from each farm in addition to data already available from other systems. One of those areas are DMI of roughage (silage, hay and other harvested crops), which is estimated based on calculated energy requirement in the MVP but could be developed so that the farmer will submit the actual amount fed to the animals.

One possible future improvement could be to develop a sub model to predict dry matter intake (DMI, kg DM per head and day) based on the IPCC method. The IPCC method would be useful when the net energy content of feeds (MJ NEL) is unknown.

Standard figures for feed losses during and after storage but before feeding should be determined after the MVP, per storage method. Discharged feeds that end up in the manure will increase nutrient content and emissions from manure management, and this should be included. It should also be determined how to handle the possibility of excessive feeding.

Waste handling of animals dying on the farm should be included in coming versions of Agrosfär.

For the MVP, it is assumed that milk-fed calves do not emit methane from enteric fermentation, and manure emissions from these calves are also neglected. This should be further looked into after the MVP.

## 7.5 Manure

Content of N, P, K in manure can be refined. We know the amount of N excreted from animals and the amount of N in stored manure (slurry, solid manure, deep bedding and urine, respectively) expressed as kg N per year. But we don't know the concentration of N in the manure expressed as kg N per ton of manure since we don't know the amount of water added to the manure (water used in the stable, rain, drainage) and hence the total amount of manure produced (ton manure per year). In addition, the P and K excretion rates can be included in Agrosfär. In the crop production, "standard" values are used, not actual from the animal production model.

## 7.6 Energy use

Total energy use is covered in the Agrosfär tool but can initially only be specified for fuel used for field operations and energy use for grain drying. In a future version of the tool information on energy use – electricity and fuel – should be allocated either to crop or animal production.

When field operations are outsourced or opposite, performed by the analysed farm for others, the tool needs to be developed to account for those cases.

Currently, drying of crops is estimated based on kg of water dried, using default values for energy required for the drying 1 kg of water or if the farmer has actual figures on energy used for drying. This method could possibly be refined after the MVP.

## 7.7 Land use change and land management

According to most LCA standards, land use change (LUC) and soil carbon changes due to land management should be included but reported separately. For purchased feed this is included in the Agrosfär model by generic numbers provided by feed producers. This could be further developed by implementing established models for assessing direct LUC in the tool.

Accounting for soil carbon changes due to land management is more difficult. Models for calculating soil carbon changes exist such as Roth-C, ICBM, Odlingsperspektiv, IPCC as well as results from long-term field trials, however guidelines for how to account for and include soil carbon changes in climate assessments is still under discussion, as the time perspective and how to ensure permanency are complex issues. Greenhouse gas protocol will release a guidance by beginning of 2023 how to account for land management (Greenhouse Gas Protocol, 2022).

## 7.8 Other land use

On a farm there will be land used for other purposes than exclusively for food production, such as fallow land, flower, riparian buffers and hedgerows, which can be grown for biodiversity preservation purposes or for other environmental enhancement purposes. When calculating GHG emissions on enterprise level such land use should also be included if it is a part of the crop, dairy or beef enterprise but is not relevant when calculating climate impact on product level.

If the farmer also grows forest, this is usually treated both economically and physically as a separate enterprise and is not included as a part of the total farm GHG assessment but can be calculated separately and will also require a separate model. However, trees can be planted in groves as a part of the crop/dairy or beef enterprise as an agroforestry measure, without the intention of deforestation for pulp production. In this case the trees can be considered as a part of the food production system and can be included in carbon

sequestration calculations in biomass or soil if such a submodel is included in the Agrosfär tool.

## 7.9 Straw

In the crop production model, removal of straw is included as it affects the nitrous oxide emissions. However, straw is not treated as a product, and no allocation between grain and straw is made. In the animal production model, straw is included in the manure emission calculations, however straw is not treated as a product and has no upstream climate impact connected to it. This means that emissions from the gathering, baling and transport of straw are not separated from crop production in the MVP, but included in the overall diesel use. In a coming version, this should be separated and allocated to the livestock production in cases where the straw is used as bedding material. This would be in line with the FAO LEAP standard, which recommends that only straw-specific steps of the production burden the straw.

## 7.10 Other inputs

Not all minor inputs have been included in the MVP. Other inputs are generally of low importance for the total GHG emissions and have not been prioritised in the first version. Other inputs not considered in the MVP, which should be considered in a coming version of the tool are:

- Plastic for silage and straw
- Bedding material other than straw (e.g. peat)
- Refrigerants for cooling of milk

## 7.11 Waste handling

Handling of waste (manure not included), e.g. the share of waste recycled, does usually not contribute significantly to carbon foot prints from agricultural products. For the MVP, handling of waste e.g. silage plastics, packaging of fertilisers and feed waste was not included, but this is a possible area for improvements in later versions of the model.

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# Appendix 1: Organic soils

Drained organic soils are a source of CO<sub>2</sub> and N<sub>2</sub>O emissions due to oxidation induced by drainage. These emissions should according to most guidelines be included in life cycle assessment. According to PEFCR, CO<sub>2</sub> emissions from drained organic soils shall be included based on a model that relates the drainage levels to annual carbon oxidation (European Commission, 2018). In PEFCR dairy minimum requirements are described and based on IPCC Tier 1: Hectares of managed or drained organic soils multiplied by a default emission factor (European Dairy Association, 2018). In the current tool the minimum requirements according to PEFCR dairy are followed as information on drainage level is not a datapoint currently collected and no easily available model relating drainage level to CO<sub>2</sub> emissions is known to us but is a possible future improvement of the tool/model.

The emission factors for organic soil (Table 6) applied in the tool are in line with the emission factors used in the Swedish national inventory (Naturvårdsverket 2021a; 2021b). For cropland the CO<sub>2</sub> emission factor is derived from IPCC Wetland supplement, further referred to as IPCC WL GL (IPCC, 2014) but reworked by Lindgren & Lundblad (2014) to only include result from countries with similar climatic conditions as Sweden. The emission factor for CO<sub>2</sub> is therefore somewhat lower than the default IPCC Tier 1 emission factor. For N<sub>2</sub>O emissions from cropland on organic soil, the emission factor is derived from IPCC without adjustments. The grassland emission factors originate from IPCC WL GL, but instead of using the default grassland emission factors, emission factors for forest are used. Swedish grasslands are often semi-natural pastures, and very rarely fertilised or intensively grazed. Whereas the studies upon which the IPCC grassland emission factors are derived from are based on countries with intensively managed grasslands. Emissions from Swedish grasslands is therefore more likely to be in line with forest land emissions than intensively managed grassland (Lindgren & Lundblad, 2014)

Table 6. Emission factors for cropland and grassland on organic soil

Land use category	Climate	Nutrient status	ton CO <sub>2</sub> -C/ha/year	kg N <sub>2</sub> O-N/ha/year
Cropland			6,1	13
Grassland	Boreal	Rich	0,93	3,2
	Boreal	Poor	0,25	0,22
	Temperate	Rich	2,6	2,8
	Temperate	Poor	2,6	2,8

The definition of organic soil is complex and does not only regard organic matter content but also thickness of the soil layer, clay content, water saturation, underlying material, and origin. IPCC doesn't provide a definition of organic soil, instead IPCC follows the FAO definition. The FAO definition of organic soils (Food and Agriculture Organization

of the United Nations (FAO), 1998) (FAO, 1998) can in a simplified matter be described by 3 criterions: 1) the soil must have a thickness of at least 10 cm 2) soils which are never water saturated should have at least 35% organic matter (OM) (by weight) 3) for soils which are subject to water saturation and have no clay, they should have at least 20 % OM, or if the soil has more than 60% clay it should have at least 30 % OM. For a soil to be classified as organic either criterion 1 and 2 must be fulfilled or criterion 1 and 3. IPCC to large extent follows the FAO definition, excluding the thickness criterion for countries to be able to use their own historical definitions of organic soil. The definition of organic soil differs between countries and disciplines, especially with respect to the minimum requirement of organic matter (IPCC, 2014).

A consequence is that countries reporting to UNFCCC can use either country specific definitions or the IPCC/FAO definition, which complicates the decision of how to define organic soil in this tool. When reporting to UNFCCC Sweden is compliant with the FAO definition (Lindahl & Lundblad, 2021) but several national definitions also exist in parallel. As an example, in the Swedish soil classification system soil with a OM content >30% is classified as organic soil. The 30% limit is derived from Swedish Jordartsnomenklatur from 1953 (Lindahl & Lundblad, see Jordartsnomenklatur 1953) . An exception is typical Swedish “gyttja” soils, which are a group of soils for which the criterion is at least 6% OM. As Sweden follows the FAO definition of organic soils when reporting to UNFCCC some of the gyttja soils not fulfilling the FAO definition are excluded in the national inventory report (Lindahl & Lundblad, 2021). Further, in soil mapping of agricultural land a soil with >40% OM is classed as organic soil, and mineral blended organic soil if OM is 20-40% (Jordbruksverket, 2010) In this tool the criterion for organic soil is set to 30% OM for drained soils. This approach is considered a simplified but pragmatic definition choice.

The emission from organic soils is estimated by the following equation:

$$CO_2 - C, \text{ or } N_2O - N \text{ on site} = \sum_{c,n} A * EF$$

Where:

A= land area of drained organic soil in a land use category in climate domain c and nutrient status n, ha

EF= emission factors for drained organic soils, by climate domain c and nutrient status n, n, tonnes C/ha/year or kg N/ha/year

The area (A) is derived in either one of three options: 1) if soil mapping data is available on field level with several datapoints, the field will be proportionally divided into % of land classified as organic soil as the % of datapoints exceeding 30% OM. If 5 out of 10 datapoints > 30% OM, 50 % of total field area will be classified as organic soil. 2) if only one datapoint at field level, the whole field will be categorised according to this datapoint 3) if no soil sampling data available, a manual choice can be done

The largest uncertainties coupled to the calculation of emissions from organic soil are the following:

- 1) The definition of organic soils varies between countries and even within countries depending on purpose, however organic soil has a large impact on the CF and thus how we define organic soils has a large impact on the results.
- 2) Emission factors, the uncertainty ranges are quite large for example N<sub>2</sub>O-N has an uncertainty range between 8,2 – 18 (compared to the EF of 13 kg N<sub>2</sub>O-N/ha/yr).
- 3) Characteristics of the emissions: The emissions are not constant nor linear to the water table (WT) level. Emissions of CO<sub>2</sub> increase with increased depth of water table level. Whereas N<sub>2</sub>O is not as dependent on WT.
- 4) National emission factors vs local prerequisites: The IPCC emission factors are suited for national level calculations. For example (Tiemeyer et al., 2020) found that their modelled and aggregated implied emission factor which considered high resolution data on type of organic soil and mean annual water table level for German organic soils aligned quite well with the IPCC Tier 1 emission factors. However, on field level these emission factors might give misguided results, as the emissions depend on parameters which can vary largely on local level.

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