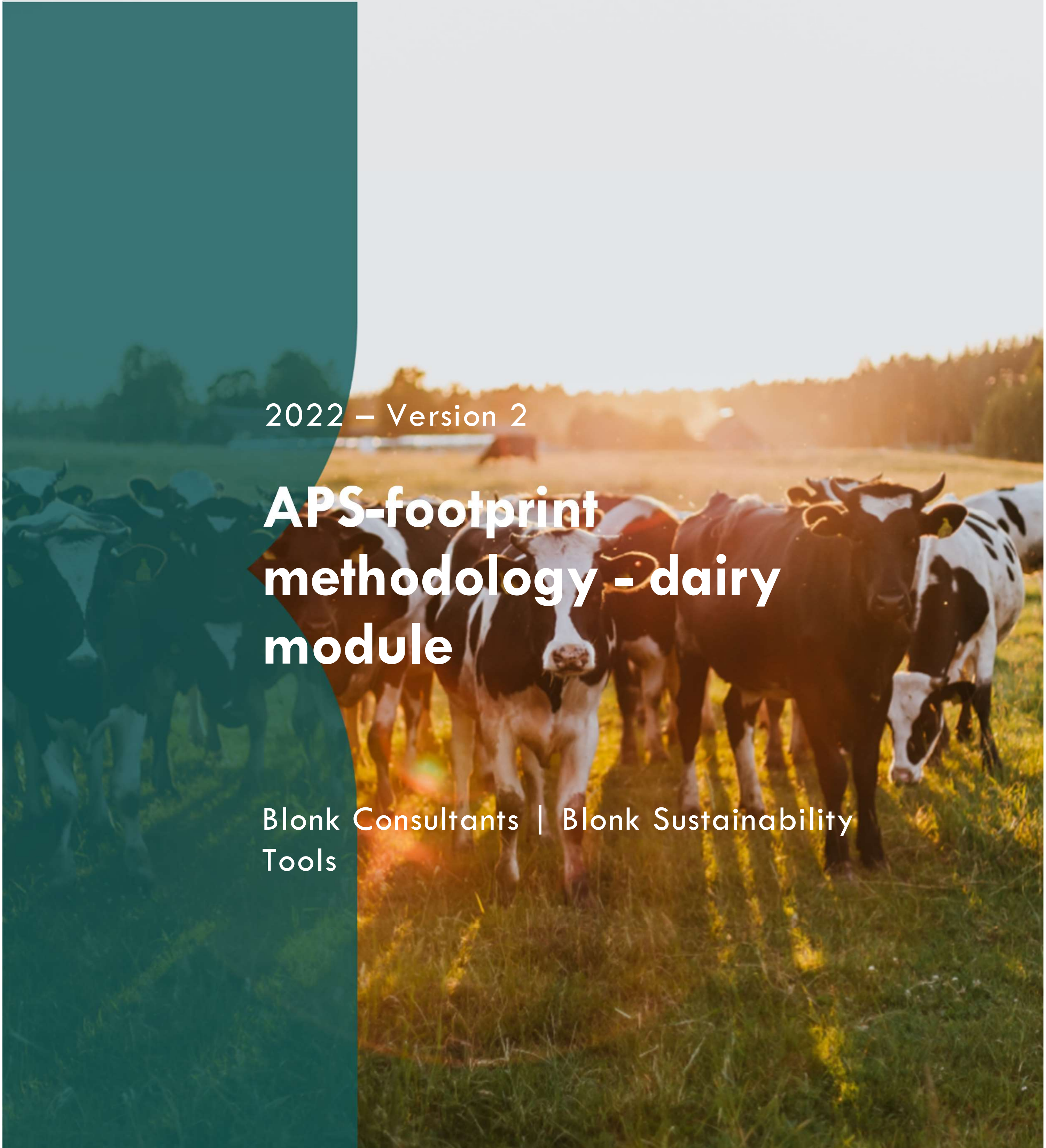

2022 – Version 2

APS-footprint methodology - dairy module

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About us

Blonk is a leading international expert in food system sustainability, inspiring and enabling the agri-food sector to give shape to sustainability. Blonk's purpose is to create a sustainable and healthy planet for current and future generations. We support organizations in understanding their environmental impact in the agri-food value chain by offering advice and developing tailored software tools based on the latest scientific developments and data.

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Table of contents

1. Introduction

This document explains the methodology used for the dairy production systems in the Animal Production System (APS) Footprint tool (APS-footprint). It is accompanying the APS-footprint tool general documentation (Blonk Consultants, 2020).

The APS-footprint framework enables to conduct environmental footprint calculations based on background datasets, parameters defined by the user and modelling of emissions according to specified standards and guidelines. Dairy systems may vary in design and environmental performance due to differences in herd composition, grazing periods, housing types, feeding regimes and manure management systems. The dairy APS module enables a user to model these different characteristics and investigate how they influence environmental impacts. The methodological framework regarding allocation, functional units, boundary definitions and emission modelling are based on published and recognized international guidelines (European Commission, 2018; European Environment Agency, 2016; IPCC, 2006b). The tool can also be used by users with only conceptual knowledge of Life Cycle Assessment.

This document describes how the activities and impacts related to animal management in the dairy APS module are modelled. The dairy APS module is connected to other APS-footprint modules (e.g. compound feed module) or to background databases to enable complete calculations of the environmental contribution of the lifecycle.

The definition of the dairy APS, and how this is connected to other the feed production system (cultivation and processing of feed ingredients) can be found on chapter 2.

The cultivation emissions modelling is currently based on the Agri-footprint 5.0 database, and is therefore aligned with the agricultural modelling rules of the PEF and the GFLI methodology (Van Paassen, Braconi, Kuling, Durlinger, & Gual, 2019b). The processing of crops into feed ingredients is also currently based on Agri-footprint 5.0 (Van Paassen, Braconi, Kuling, Durlinger, & Gual, 2019a) and is also compliant to the Feed PEFCR modelling rules.

Chapter 3 defines and explains the parameters required in the dairy APS module (herd composition data: chapter 3.1, input data: chapter 3.2, output data: chapter 3.3). The parameters described there need to be defined by the user to calculate the LCIA. Pre-defined systems (reference systems) can be also selected by the user. These are described in chapter 5.

Chapter 4 describes the modelling of nutrient excretions, emissions from enteric fermentation and emissions connected to manure management. It also contains default values for the required parameters.

Identified limitations of the APS-footprint tool and its methodology are mainly the lack of capability of accounting for changes happening outside the boundaries, the lack of detailed herd or animal metabolism model (therefore relying on user inputs) and current lack of Data Quality Rating (DQR) system or uncertainty analysis. More detailed information can be found in chapter 3.3 of the *APS-footprint tool general methodology* document (Blonk Consultants, 2020).

2. System definition

The dairy farm system consists of all cradle to gate activities related to feeding, growing, and housing the dairy cattle and harvesting the animal products at the farm. The dairy farm system is a mixed crop-livestock system, meaning that the production of part of the animal diet takes place at the farm. In particular, roughages are largely fertilized with manure coming from the animal housing or after an eventual storage. Once harvested, roughages can go through some processing step on farm (e.g. silage production) and are then fed to the animal. An even shorter cycle is pasture: animals release manure on grassland, and directly feed themselves with fresh grass. Such material loops increase the complexity of the modelling exercise.

We define the dairy Animal Production System (APS) module as a narrower system compared to the mixed crop-livestock dairy system (summary in Figure 1, in more detail in Table 1). The dairy APS boundaries are set at inputs at housing (compound feed, roughages, water and energy), feed input during pasture (fresh grass) and outputs (milk, culled animals and manure after its management). Manure management also needs to be included. Currently, manure excretions is modelled in the dairy APS module as released at housing, yard and pasture (as suggested by EMEP/EEA, 2016):

- Housing manure management models the emissions (and nutrient composition change) during housing and eventual storage of manure; the subsequent fate of manure is assumed to be always land application. Impact of manure leaving the housing/storage is not considered in the dairy APS but allocated to the crop cultivation (included in the crop cultivation background LCI). This means that the material loop of manure produced at the animal housing and applied on on-farm cultivations is not modelled directly. The assumption here is that over (or under) production of manure compared to the manure need for on-farm cultivations will result in exporting manure outside the farm (or importing manure from outside).
- Yard manure management account for emissions at yard that are allocated to the dairy APS. In this case also, manure fate is assumed to be land application, and the emissions during application are allocated to the cultivated crop.
- Pasture manure management considers emissions from manure released on pasture and include them in the dairy APS. This means that the production of the fresh grass input should not include manure application, to avoid double-counting.

The inputs to the APS systems are modelled in the APS-footprint tool based on background databases (currently Agri-footprint 5.0[1]).

The herd is modelled as a closed system in steady state, where the number of dairy cows remains constant and no purchase of animals is taking place. The APS-footprint tool does not include a module for modelling herd population dynamics or biophysical growth and production curves of the animals. Therefore, the animal herd inputs required can be defined by using herd and biophysical models externally to the tool to simulate the animal system (this is particularly relevant for fresh grass input). Other sources of animal herd data might be: primary farm information, statistics, scientific publications or the reference systems available in APS-footprint tool.

The outputs of the APS can enter another system, such as milk processing, slaughtering, veal/beef production and manure fate (currently only land application). There is no intention to develop an APS-footprint module for dairy processing. Including a beef module, a slaughtering module and an expansion of the choices for manure fates (systems boundary expansions) are being investigated for future implementations/updates.

[1] One modification to the original Agri-footprint 5 dataset is applied for grass production ("Grass, at dairy farm/NL Economic") to remove the emissions from manure application. Two processes (hay input used as single ingredient feed input and saw dust used as bedding) are based on Ecoinvent 3.5 APOS database.

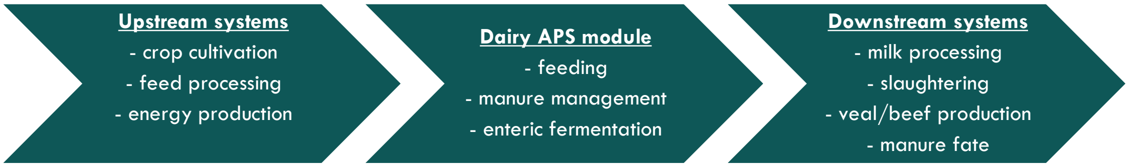

FIGURE 1: SYSTEM DIAGRAM OF THE DAIRY SYSTEM.

The choice for inclusion or exclusion of the processes is based on the recommendations in PEFCR's or LEAP guidelines. The process of determining inclusion or exclusion in PEFCR's was based on impact contribution (significance) and data availability.

Activities/ processes	Included	Excluded
Crop cultivation	• Fuels use • Electricity use • Inorganic N, P, K Fertilizer use • Organic fertilizer (manure and others) use (excluded for fresh grass) • Lime use • Use of pesticides on the field and at storage • Use of irrigation water • Seed use • Depreciation of capital goods for machinery and storage	• Other consumables used during cultivation (e.g. micronutrient fertilizers, nitrification inhibitors) • Activities related to living at the farm • Activities related to other business (e.g. producing wind energy) • Non-agricultural activities related to the producing company (e.g. accounting department).
Feed processing	• Crop input mix of originating countries • Transport (distance per transport means) • Fuels use • Heat/ Electricity use • Water use • Wastewater treatment only for wet processes • Organic waste & losses • Auxiliary materials (processing aids)	• Auxiliary materials adding up to less than 1% of mass contribution • Consumables used at the plant not used as a raw material or auxiliary material (e.g. preservatives, cleaning agents) • Depreciation of capital goods • Non-agricultural activities related to the producing company (e.g. accounting department).
Dairy APS	• Youngstock • Feed materials • Transport (distance per transport means) • Fuels use • Electricity use • Use of water	• Other consumables used at the farm other than animals and feed (e.g. plastics for covering roughage) • Depreciation of capital goods • Veterinary service • Non-agricultural activities related to the producing company (e.g. accounting department).

TABLE 1. OVERVIEW OF THE INCLUDED AND EXCLUDED ACTIVITIES IN DE APS-FOOTPRINT MODULE FOR DAIRY SYSTEMS

2.1 Upstream systems connected to the dairy APS

Currently, Agri-footprint 5.0 (Van Paassen et al., 2019a, 2019b) is the main source of data on feed ingredients, additives, energy and other inputs. Other databases, such as the GFLI database or EF database will be linked to APS-footprint in the future. It is also possible to import user specific system process LCI data related to feed and energy production into APS-footprint.

Cultivation datasets in Agri-footprint include land occupation, water inputs, fuel production and burning during agricultural machine use, electricity production, inorganic fertilizers production, pesticide production, capital goods and emissions at transport of input, impact of capital goods production, emissions from pesticide, manure, urea and inorganic fertilizers (N2O direct and indirect, C2O and NH3 to air; nitrate, phosphorus and heavy metals leaching to water; heavy metals emission to air).

The energy data set contains the whole supply chain of the fuels from exploration over extraction and preparation to transport of fuels to the power plants. All relevant and known transport processes used are included. Overseas transports including rail and truck transport to and from major ports for imported bulk resources are included. Furthermore, all relevant and known pipeline and / or tanker transport of gases and oil imports are included. Coal, crude oil, natural gas and uranium production are modelled according to the specific import situation. Diesel, gasoline, technical gases, fuel oils, basic oils and residues production such as bitumen are modelled via a country-specific, refinery parameterized model. Furthermore, Specific technology standards of heat plants regarding efficiency, firing technology, flue-gas desulphurisation, NOx removal and dedusting are included. The data set contains the whole supply chain of the fuels from exploration over extraction and preparation to transport of fuels to the heat plants. Furthermore, the data set comprises the infrastructure as well as end-of-life of the plant.

For water input, the following operations are modelled in the background database: aeration (oxidation), filtration, water softening (decarbonisation) and disinfection, all based on average European technologies and in accordance with the value found in the literature. The result of these operations is potable water from groundwater for all kind of applications. The LCI of water cover of at least 95 % of mass and energy of the input and output flows, and 98 % of their environmental relevance (according to expert judgement).

2.2 Downstream systems connected to the dairy APS

The outputs of the dairy farm are raw milk, live animal leaving the farm (dairy cows and calves) and manure.

Milk usually is connected to a processing stage and a subsequent distribution channel. Various types of dairy products can be derived from it, also based on the milk characteristics. The modelling of these systems is not included in the APS-footprint tool.

Dairy cows and calves can be slaughtered with subsequent production of various types of animal products with specific uses and connected to various supply chains. The modelling of these systems is not included in the APS-footprint tool (a slaughtering module is on development). Calves could also enter a calves/beef animal system with subsequent slaughtering. Such a module is not available in the APS-footprint tool yet.

Manure can have various types of fates. Manure released during pasture is included in the boundaries of the dairy APS. For the other manure, we assume only land application and the manure is considered to be a residual output of the dairy APS. Residual streams consider no allocation, while manure input and emissions during on-farm application are included in the background dataset. This means that a direct link between manure from the management system and on-farm cultivation is not in place. In case of other types of fate (e.g. manure burning, manure digestion) a system boundary expansion of the dairy APS would be necessary (currently under development).

3. Required parameters

All the parameters described in this chapter have to be filled in by the user in order to calculate a complete LCIA (overview of unit process connection on Table 13, 5.2Appendix I). It is also possible to use the reference systems available (described in chapter 5).

3.1 Herd composition

In the dairy APS module, it is necessary to define the animal population (animal type and number) associated with the production system. In the dairy module of the APS-footprint tool, four animal types are defined:

- **Dairy Cow**
  Dairy cows include the milk-producing cattle. Dairy cows start producing milk after giving birth to their first calf, which is usually during their third year of life. Dairy cows are slaughtered at around 4-5 years of age. This animal category includes both dairy cow in lactation and dairy cow in dry period. The weight of dairy cows can vary. Since APS-footprint assumes a system at equilibrium and an average dairy cow weight, it is assumed that there is no weight accumulation of the herd in this stage.
- **Calves < 1 year**
  Female calves that are not slaughtered are further raised for future replacement of dairy cows. In their first year of life, the weight grows from circa 50 kg to around 300 kg.
- **Calves 1-2 years**
  In this stage, female calves are raised from 1 year up to 2 years of age. Animals in this stage grow from approximately 300 kg to 600 kg.
- **Heifers**
  In this stage, female calves are raised from 2 year of age up to calving age. The latter is the age in which it gives birth to calves for the first time, followed by its first lactation period. Calving age varies from 24 up to 26 months in average. This means that heifers are considered as such for a short period of time (few months).
- **Bulls**
  Bulls can also be present on a farm. The average lifespan of bulls can vary between 3 to 5 or more years. They usually weigh more than the dairy cows, and their population is very small since one bull can inseminate many cows. In modern systems, bulls might not present since artificial insemination is a common practice. Artificial insemination is not modelled in the dairy APS module (ideally, semen should be available as input, with a connected background process).

The number of animals at farm is based on a production period of one year and the average number of present animals is requested as input for APS-footprint. For each animal type, this is called Annual Average Population (AAP). This means that the heifer population should account for their short period. For example, if in one year 100 animals enter the heifer period of 2 months (calving age of 26 months), then the heifer AAP will be 100 / (12/2) = 16.6 heifers. Along the production, it is possible that animals die (e.g. due to diseases). Mortality rates should also be considered and excluded from the AAP, by considering where the death happens. In the previous example, if heifers have a 4% mortality rate that happens in average at half of the cycle, then the calculated AAP would be 16.6 * (1 – 0.04/2) = 16.3.

We suggest basing the AAP on primary data derived from an on-farm herd census. If this is not possible, we suggest using or developing a herd population model. This should be based on animal replacement rates for each animal type together with mortality rates and eventual managerial decisions. A fall-back approach would be to use data available in statistics, scientific literature or to use the available reference systems in the APS-footprint tool (described in chapter 5).

3.2 Inputs

Quantification of the inputs to the system are required by the module. These can be summarized in feed, water, bedding material and energy.

3.2.1 Feed

Information on feed amount and nutrient content are required as input for the calculations.

The feed inputs need to be defined as kg feed (as is) every AAP for 1 year.

Two types of feed are distinguished in the dairy APS module: compound feeds and single ingredients:

- Compound feeds are defined in the compound feed module of the APS-footprint tool. The compound feed formulation can be defined together with inbound (from ingredient production to compounding feed mill) and outbound (from compounding feed mill to farm) transportation and energy use. APS default ingredient list is based on Agri-footprint 5.0 (Van Paassen et al., 2019a). Ingredients can be uploaded upon user request.
- Single ingredients production is also based on Agri-footprint 5.0 (Van Paassen et al., 2019a). Single ingredients include feed that are directly fed to animals, without the process of including them in a compound feed. This usually happens since they are produced at farm. These include roughages (fresh grass, grass silage, maize silage, straw and hay), wet co-products (spent brewers and distillers grain) and crops (grains, beets and legumes).

Besides the amount of different types of feed fed, some feed nutrition related characteristics have to be defined by the user, such as: digestibility, overall gross energy (GE) intake, amount of silage in overall diet and crude protein content in overall diet. Such characteristic should be calculated as a weighted average of the overall diet based on the characteristic at product level. How these relate to the emissions modelling is explained in chapter 4.

We suggest deriving the feed input parameters (ration and characteristics) from on-farm primary data. If this is not possible, we suggest using or developing a biophysical model able to predict the feed requirements for each animal type. This should be based on the animal weight and growth, milk production, milk nutritional characteristics and calves production. The model should estimate the energy and nutritional characteristic of the outputs, model losses (from maintenance, activity, lactation, pregnancy, manure and urine) and derive the input requirements (for more detail look into IPCC (2006a) or Johnson (2016)). In particular, this modelling approach is important for estimating fresh grass input, since it is not possible to determine it through measuring. A fall-back approach would be to use data available in statistics, scientific literature or to use the available reference systems in the APS-footprint tool (described in chapter 5).

3.2.2 Water

There are multiple types of water use on the dairy farm. Water is consumed by the animals as drinking water. Water is also used on the farm for management purposes like cleaning the milking area. In practice, water can also be used for irrigation of crops. Irrigation water is already included in the background LCI, such that the total water input on the dairy farm is equal to all water use except the water used for irrigation of crops.

3.2.3 Bedding

Bedding is used in the stable of the dairy cows. Two types of bedding can be selected in APS-footprint: saw dust and straw. These types of bedding are commonly used in typical dairy systems.

3.2.4 Energy

There are several types of energy use on the dairy farm. A main source of energy is electricity (cooling is important), but other fuels, like natural gas and diesel are also used. Electricity use includes all types of farm associated activities. Typical activities are cooling, lighting, ventilation, automated feed and water rationing, automated milking systems, and water recirculation.

In the APS-footprint, electricity production is based on Agri-footprint 5.0, that uses ELCD processes (Van Paassen et al., 2019a). Agri-footprint processes for electricity reflect national grid and, based on the location selected, a specific national grid electricity production process is selected. This means that is not currently possible to consider specific production technologies (e.g. wind or solar electricity).

Natural gas and diesel are mainly used for the heating system or farm machinery (including the machinery used to store and collect roughage). Diesel used for machines during crop cultivation are not considered here, since this is already included in the cultivation background LCI.

3.3 Outputs

The main output of the dairy APS is raw milk. Required parameters are the yearly farm milk production, the fat content, and the protein content of the milk. Milk losses at farm and milk that is not suitable for consumption (e.g. milk discarded because contaminated by antibiotics or high microbial load) is not accounted in the raw milk output. Also, eventual dairy processing on-farm cannot be modelled in the dairy APS module.

The dairy APS module also accounts for live animal leaving the farm. Dairy cows are removed from the herd for various reasons, usually connected to decrease in productivity. These are usually culled. A dairy farm also produces male calves and quite often some surplus female calves which are also co-products of the dairy farm system. These can be slaughtered directly or can be sold for further growth in other production systems. The total amount of liveweight (kg) leaving the dairy APS is required (including both replaced cows and calves).

Mortality output is currently not considered in the dairy APS module. We intend to include the possibility to define the output of mortalities (kg) and to model the fate of mortalities (e.g. rendering, composting, incineration) in the future.

Manure is also an output of the dairy APS module, possibly mixed with bedding material. In the APS is considered as a residual stream. When manure leaves the dairy APS, the only fate assumed is land application. This is modelled in the background, and the user is not requested to specify the amount or characteristic of the manure leaving the farm.

Non-dairy products sold at farm and on-farm energy production cannot be modelled in the dairy APS module.

3.3.1 Functional unit (reference unit)

The functional unit is 1 kilogram of Fat-Protein Corrected Milk (FPCM) (corrected to 4% fat and 3.3% protein) as calculated in PEFCR dairy guidelines (European Commission, 2018):

$$FPCM\left(\frac{kg}{yr}\right) = Production\left(\frac{kg}{yr}\right) x\ (0.1226\ x\ True\ Fat\% + 0.0776\ x\ True\ Protein\% + 0.2534)$$

Where:

- FPCM is the amount of Fat-Protein Corrected Milk (kg year^{-1});
- Production is the amount of milk produced (kg year^{-1});
- True fat is the content of fat present in the produced milk (%);
- True protein in the content if protein in the produced milk (%);
- 0.1226, 0.0776 and 0.2534 are parameters calculated based on regression. More information on how are calculated can be found on IDF (2010).

3.3.2 Allocation

Allocation is used to distribute the overall environmental impacts to the different outputs: milk and animal liveweight (aggregate of replaced dairy cows and sold calves). The dairy module of APS-footprint uses biophysical allocation to calculate the environmental impact of the two co-products. This type of allocation is extensively used in the dairy sector. It was developed by the International Dairy Association (IDF, 2010) and was suggested by the dairy PEFCR (European Commission, 2018):

$$AF = 1 - 6.04\ x\ \frac{M_{meat}}{M_{milk}},$$

Were AF is the Allocation Factor of milk, M_{meat} is the mass of live weight of all animal sold including bull, calves and culled mature animals per year, and M_{milk} is the mass if FPCM sold per year. The allocation for Meat can be calculated as 1 - AF.

According to the dairy PEFCR, manure can be considered as:

- Residual product: manure is exported from the farm as product with no economic value. No allocation: burden allocated to other products produced at farm, including pre-treatment of manure.
- Co-product: manure is exported from the farm as product with economic value. Economic allocation of the upstream burden shall be used for manure by using the relative economic value of manure compared to

milk and live animals at the farm gate, provided proof is given that it is sold and used for fertiliser replacement at optimal rates for crops (i.e. if excess is applied it is treated as a Residual). Biophysical allocation based on IDF rules shall be applied to allocate the remaining emissions between milk and live animals. Environmental burden form manure treatment is fully allocated to manure as coproduct.

- Waste: Manure is not used to produce products but treated as waste. Apply end-of-life formula and allocate environmental burden to other products produced on the farm, including treatment of manure.

In the dairy APS module manure is always treated as a residual product.

4. Emission modelling

The core of the dairy APS module is the calculation of the emissions released to nature.

The emissions modelled in the dairy APS module are:

- Methane (CH_4) from enteric fermentation;
- CH_4 from manure;
- Direct dinitrogen monoxide (also called nitrous oxide) (N_2O) from manure;
- Indirect N_2O from leaching of manure;
- Indirect N_2O from volatilization of ammonia (NH_3) and nitrogen oxides (NO_x);
- Non-methane volatile organic compounds (NMVOC) from manure;
- Particulate matter ($PM_{2.5}$ and PM_{10}) from manure.

In APS-footprint, the modelling of emissions is based on published and recognized guidelines, methodologies, reports (like the one accompanying national inventory reports) or peer-reviewed scientific studies.

Leaching of nitrate (NO_3^-) and phosphorus (P), and emissions of heavy metals (e.g. Cu, Zn) are currently not modelled in the dairy APS module. This is mainly because methodologies for these emissions are complex and not well developed, and therefore, not covered by any recognized and accepted methodology. This is a large limitation for the correctness and interpretation of impact related to marine eutrophication, freshwater eutrophication, and toxicity related impacts. Expansions of the dairy APS module with the modelling of N and P leaching and heavy metals is currently under development for future updates.

Carbon sequestration and refrigerants emitted to air during milk cooling are excluded, which is in line with the dairy PEFCR ((European Commission, 2018)).

As extensively explained in the general methodology document (Blonk Consultants, 2020), each APS-footprint module is designed to handle multiple emission calculation APS method. An APS method is a set of models that estimate the above-mentioned emissions. This means that the LCIA of a defined animal system can be calculated with different methodological approaches regarding emissions calculation. Currently, one baseline APS method is available for the dairy APS module. This is the PEFCR Dairy 2018 method that is completely based on the dairy PEFCR framework (European Commission, 2018). The development of other APS methods is currently investigated (e.g. APS method based on the Dutch National Inventory Report).

The different models that compose the baseline PEFCR Dairy 2018 method calculate the considered emissions based on the parameters defined by the user plus additional default parameters (extrapolated from the dairy PEFCR framework).

Depending on the Tier level, the considered models calculate emissions with different approaches. The difference between the three Tier levels can sometime be difficult to define. This is because IPCC (2006b) and EMEP/EEA (2016) are guideline that give indications on how countries should estimate their yearly emissions. This means that different Tier levels can be sometimes (e.g. for direct N_2O emissions) based on the same equation, but dependent on the data input used (country-specific vs non country-specific). The APS module use parameters defined by the users, so they can be very specific (primary data) or really generic data (proxy). In general, we defined the Tier level as follow:

- Tier 1 emissions model: calculates the emission based on a default emissions factor (EF) that is based on the average number of animals present on farm (e.g. 0.41 kg $PM_{2.5}$/dairy cow AAP/year)
- Tier 2 emissions model: usually a two-step approach, were at first an excretion is calculated (e.g. Nitrogen - N - excretion) based on a full or partial balance. Full balance calculations account for all input and output flows. Partial balances simplify the model by using e.g. a default retention factor. The second step uses one or multiple default EFs to translate the excretion into emissions (e.g. kg N_2O-N /kg N excreted)
- Tier 3 emissions model: uses complex biophysical model to estimates excretions, together with EFs that are measured or based on more advanced country specific methodologies, compared to the defaults.

Table 2 summarizes the model used for excretion and emissions calculation in the PEFCR Dairy 2018 method of the dairy APS module. This baseline setup of the method uses a model that considers feed conversion balances and is applied to all farm systems regardless of their origin. The emission quantification of the PEFCR Dairy 2018 method is built on the following related documents:

- Product Environmental Footprint Category Rules for Dairy Products (European Commission, 2018). This document was developed by the European Commission to standardize the LCA framework for dairy products, in the context of the PEFCR project and is a further concretization of the FAO LEAP guidelines for large ruminants (FAO LEAP, 2016) and the IDF guidelines (IDF, 2010) for calculating GHG emissions.
- Chapter 3.B of EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2016). This document was published by the European Environment Agency to help government bodies to measure air pollution. It proposes calculation methods for nitrogen volatilization, Non-Methane Volatile Organic Compounds (NMVOC) emissions and Particulate Matters (PM) emissions (European Environment Agency, 2016).
- Chapter 10 of IPCC (2006b) on emissions from livestock and manure management (IPCC, 2006a). The Intergovernmental Panel on Climate Change (IPCC) developed calculation methods and standards to estimate the climate change impact for various industry sectors. This chapter focuses on enteric methane production in animal farms and methane and nitrous oxide emissions from manure management.

TABLE 2: OVERVIEW OF THE TIER MODEL AND SOURCES FOR THE EXCRETION AND EMISSIONS MODELLING IN THE DAIRY APS MODULE.

Excretions and emissions	Baseline method: PEFCR Dairy 2018	Section
N excretion (N_E)	IPCC Tier 2	4.1.1
TAN[1] excretion (TAN_E)	EMEP/EEA	4.1.2
VS[2] excretion (VS_E)	IPCC Tier 2	4.2.1
CH_4 enteric	IPCC Tier 2	4.3.1
CH_4 manure	IPCC Tier 2	0
Direct N_2O emissions	IPCC Tier 2	4.5.1
Indirect N_2O emissions	IPCC Tier 2	4.6.1
NH_3 emissions	EMEP/EEA Tier 2	4.7.1
NO_x emissions	EMEP/EEA Tier 2	4.8.1
NMVOC emissions	EMEP/EEA Tier 2	4.9.1
$PM_{2.5}$ and PM_{10} emissions	EMEP/EEA Tier 1	4.10.1

[1] Total Ammonia Nitrogen. [2] Volatile Solids.

For the calculation of manure related emissions, data on geography (average annual temperatures and level of development of the country) are needed. The average annual temperature has to be set by the user, while the level of development of the country is based on UN report (United Nations, 2012).

Once the total N, TAN and VS excretion amounts are quantified, it is necessary to account for the shares of excreta deposition at the different locations on the farm. For the emissions calculated with EMEP/EEA (2016) guidelines, this is done by defining the time spent on grazing, spent on open yard areas, and spent inside the housing:

- Time spent on grazing is defined as the period spent by the animal on grassland or other pastures.
- Time spent on open yards is defined as the period spent by the animal on feedlot (or drylot) or spent on open areas while waiting for milking.
- Time spent on housing is defined as the period spent by the animal in the housing system where feed, water and protection from relevant environmental conditions are provided. Housing systems vary greatly worldwide, from shed to barns.

The time spent in each of the three locations is expressed as a fraction of the overall year (therefore summing up to 1), and has to be set by the user. These parameters are used to define the amount of manure excreted on each location. The assumption taken is that excretion behaviours of animals is not influenced by their location.

As already explained in chapter 1, the emissions from manure excreted in housing are taken into account, along with the emissions during manure storage, up until the manure leaving the storage site. Therefore, emissions from application are not considered in this chapter, but included in the background cultivation dataset. The emissions from open yard are also included up until the manure leaves the lot or yard (only relevant for emissions calculated with EMEP/EEA (2016)). The emissions from manure released on pasture are accounted for (only relevant for emissions calculated with EMEP/EEA (2016)). The details of each emissions calculation - and of where each emission take place in three considered locations - are indicated in the specific section related to an excretion or emission modelling.

In the current version of dairy APS module, emissions calculated according to IPCC (2006a) only consider one manure management per animal type: the housing management as defined by the user. This means that for N_2O and CH_4 emissions, N and Volatile Solids (VS) excretion are assumed to take place only at housing, with one type of manure management system in place. This simplification is an important limitation of the current version of the dairy module. An update of the manure management approach is under development and will be implemented in the first and second quarters of 2021 (step-by-step implementation).

Emission reduction systems and variability in housing systems are currently not considered in the manure management of the dairy APS module. A way of taking them into account is through the modelling of an 'interventions' in APS-footprint. As explained in in the general methodology document (Blonk Consultants, 2020), the APS-footprint tool is designed to add an intervention layer on top of the baseline system. In this case, the abatement technology (e.g. manure acidification, air washer or innovative housing system) can be considered as an intervention. For this, the share (%) of emission reduction of the technology needs to be defined. All emissions calculated by the dairy APS module can be influenced by the user through the intervention modelling.

Each APS-footprint module is designed to model interventions to the animal production systems. Many interventions act on feed intake, feed digestibility or productivity. These changes result in changes in excretions (mass, nitrogen, volatile solids etc). To account for this, a system expansion, where the consequential change in nutrient during manure spreading (or other fates) availability should be accounted. A way of accounting this would be to consider the avoided production (or higher need) of inorganic fertilizers. Such implications are not currently accounted in the dairy APS module.

4.1 N excretion

4.1.1 Baseline: PEFCR Dairy 2018 - IPCC Tier 2

The IPCC Tier 2 (IPCC, 2006a) approach for estimating N excretion is based on a mass balance and is dependent on the total annual N intake and N retention of the animals. The N intake can be estimated from the annual amount of feed ingested by the animal, and the protein content of that feed. Annual N retention (i.e., the fraction of N intake that is retained by the animal for the production of meat and milk) express the efficiency of the animal to produce animal protein from feed protein (IPCC, 2006a).

$$N_{E\,(T)} = N_{intake\,(T)} * (1 - N_{retention\_rate\,(T)})$$

$$N_{intake\,(T)} = \frac{GE_{(T)} * AAP_{(T)}}{18.45} * \frac{CP\%_{(T)}/100}{6.25}$$

Where:

- $N_{E\,(T)}$ is the N excretion per animal category T (kg N year^{-1});
- $N_{intake\,(T)}$ is the N intake per animal category T (kg N year^{-1});
- $N_{retention\_rate\,(T)}$ is N retention: the fraction of N intake that is retained by the animal for the production of meat and milk per animal category T (dimensionless);
- $GE_{(T)}$ is the overall diet gross energy intake per animal for animal type T (MJ animals^{-1} year^{-1});
- $AAP_{(T)}$ is the average annual population per animal type T (animals);
- 18.45 is the conversion factor for dietary GE in kg of dry matter (MJ kg^{-1});
- CP% is the crude protein content in the overall diet fed to the animal type T (%);
- 6.25 is the conversion factor from kg of dietary crude protein to kg of dietary N (kg-protein kg-N^{-1}).

The sum of the N excretion from various animal types results in the overall farm N excretion.

All the parameter needed for the equations have to be specified by the user, except for the ones for which IPCC (2006a) default values are used (20% for dairy cows and of 7% for other cattle at the dairy farm). One important limitation of using defaults for the annual retention is that interventions that affect N retention will not be captured in the N excretion. Improving the equations to model a full Nitrogen balance (based on data on N output) is a high priority for the future updates of the PEFCR dairy 2018 method in APS-footprint.

a. TAN excretion

4.1.2 Baseline: PEFCR Dairy 2018 - EMEP/ EEA

To calculate the Total Ammonia Nitrogen (TAN), EMEP/EEA (European Environment Agency, 2016) suggest to multiply the N excretion by the proportion of the N excreted as TAN. The current default value used for all cattle is 0.6 kg TAN/kg N (EMEP/EEA, 2016). If detailed national procedures for deriving N excretion rates that provide the proportion of N excreted as TAN are available, these should be used according to EMEP/EEA (2016). Therefore, in the future, when country specific APS methods will be developed, country specific methodologies for TAN excretion will be taken into account.

4.2 VS excretion

4.2.1 Baseline: PEFCR Dairy 2018 - IPCC Tier 2

The calculation of Volatile Solids (VS) excretion using IPCC Tier 2 approach (IPCC, 2006a) is based on feed digestibility; therefore, it can take into account an increase in digestibility due to the use of additives:

$$VS_{(T)} = \left[GE_{(T)} * AAP_{(T)} \; * \left(1 - \frac{DE\%_{(T)}}{100}\right) + \left(UE * GE_{(T)} * AAP_{(T)}\right)\right] * \left(\frac{1-A}{18.45}\right)$$

Where:

- $VS_{(T)}$ is total volatile solids excretion per animal type T (kg VS year^{-1});
- $GE_{(T)}$ is the overall diet gross energy intake per animal type T (MJ animals^{-1} year^{-1});
- $AAP_{(T)}$ is the average annual population per animal type T (animals);
- $DE\%_{(T)}$ is the diet digestibility of animal type T expressed as a fraction of gross energy (%). This parameter has to be set by the user18.45 is the conversion factor for dietary GE in kg of dry matter (MJ kg^{-1}).
- Table 3 can be used as indication in case this parameter is not available;
- UE is the urinary energy expressed as a fraction of gross energy. Typical value for ruminant is 0.04, and this is used as background default;
- A is the ash content of manure (kg/kg, default value: 0.1, from IPCC (2006a));
- 18.45 is the conversion factor for dietary GE in kg of dry matter (MJ kg^{-1}).

TABLE 3 GENERIC (BREED, COUNTRY AND DIET) DIET DIGESTIBILITY DEFAULT RANGES FROM IPCC CAN BE USED AS REFERENCE FOR THE USER.

Dairy type – system	DE% default from IPCC
Feedlot animals fed with > 90% concentrate diet	75 - 85%
Pasture fed animals	55 - 75%
Animals fed – low quality forage	45 - 55%

4.3 Methane enteric fermentation

4.3.1 Baseline: PEFCR Dairy 2018 - IPCC Tier 2

The approach of IPCC Tier 2 (IPCC, 2006a) calculates emissions due to enteric fermentation according to the following formula:

$$CH_{4\,ent\,(T)} = GE_{(T)} * AAP_{(T)} * \frac{Y_{m\,(T,L)}}{55.65}$$

Where:

- $CH_{4\,ent\,(T)}$ is the methane emission from enteric fermentation for animal type T (kg-CH_4 year^{-1});
- $GE_{(T)}$ is the overall diet gross energy intake per animal type T (MJ animals^{-1} year^{-1});
- $AAP_{(T)}$ is the average annual population per animal type T (animals);

- $Y_{m\,(T,L)}$ is the methane conversion factor for animal type T and location L (%);
- 55.65 is the energy content of methane (MJ kg-CH_4^{-1}) (IPCC, 2006a).

The gross energy intake is one of the feed parameters required by the model, as explained in chapter 3.2.1. The methane conversion factor Y_m ranges from 5.5% to 7.5%, dependent on the quality of roughage and compound feed that is fed. Based on the regional description on Table 10.11 of IPCC (2006a) or available literature, default parameters have been defined (Table 4).

TABLE 4 METHANE CONVERSION FACTOR USED IN THE BASELINE METHOD.

Region	Animal type	$Y_{m\,(T,L)}$	Source
Western Europe and North America	All cattle	5.5%	Table 10.11 of IPCC (2006a)
Indian subcontinent countries	All cattle	7.5%	Table 10.11 of IPCC (2006a)
US - California	Heifer	5.9%	(Mangino, Peterson, & Jacobs, 2003)
US - California	Dairy cows	4.8%	(Mangino et al., 2003)
Rest of the world	All cattle	6.5%	Table 10.11 of IPCC (2006a)

4.4 Methane emissions (from manure management)

4.4.1 Baseline: PEFCR Dairy 2018 - IPCC Tier 2

IPCC (2006a) Tier 2 uses the following formula to calculate methane emissions from manure management:

$$CH_{4\,man\,(S,T)} = VS_{(T)} * B_{O\,(T,k)} * \rho * \sum_{S,k} \frac{MCF_{S,k}}{100} * MS_{(T,S,k)}$$

Where:

- $CH_{4\,man\,(T)}$ is the yearly methane emission from manure management S per animal type T (kg year^{-1});
- $VS_{(T)}$ is the amount of yearly volatile solids per animal type T (kg year^{-1}) (chapter 4.2.1);
- $B_{O\,(T)}$ is the maximum emissions potential (m^3-CH4 kg-VS^{-1}) (provided in IPCC (2006a) Table 10A-4 and 10A-5, dependent on livestock type T and climate region k);
- $MCF_{S,k}$ is the integrated methane conversion factor (provided in IPCC (2006a) Table 10A-4 and 10A-5, dependent on livestock type T, manure management system and temperature k);
- ρ is the density of methane (0.67 kg CH_4/m^3) (IPCC, 2006a);
- $MS_{(T,S,k)}$ is the fraction of manure (from livestock type T and in climate region k) handled using a specific manure management system.

4.5 Direct N_2O emissions (from manure management)

4.5.1 Baseline: PEFCR Dairy 2018 - IPCC Tier 2

IPCC (2006a) Tier 2 uses the following formula to calculate direct nitrous oxide emissions from manure management:

$$N_2O_{d\,(S,T)} = N_{E\,(T)} * EF_{N2O.d\,(S)} * \left(\frac{44}{28}\right)$$

Where:

- $N_2O_{d\,(T)}$ is the direct nitrous oxide emissions from manure management S per animal type T (kg year^{-1});
- $N_{E\,(T)}$ is the nitrogen excretion per animal type T (kg year^{-1});
- $EF_{N2O.d\,(S)}$ is the emission factor (kg N_2O-N/kg N) for the relevant manure management system S. Based on IPCC (2006a)Table 10.21;
- the factor 44/28 is to convert mass of N_2O-N to mass of N_2O.

4.6 Indirect N_2O emissions (from manure management)

4.6.1 Baseline: PEFCR Dairy 2018 - IPCC Tier 2

Indirect N_2O emissions are coming from two types of mechanisms: from volatilization of NH_3 and NO_x, and from NO_3^- leaching:

$$N_2O_{i.v\,(S,T)} = N_{E\,(T)} * \frac{Frac_{GasM\,(S,T)}}{100} * EF_{N2O.i.v} * \left(\frac{44}{28}\right)$$

$$N_2O_{i.l\,(S,T)} = N_{E\,(T)} * \frac{Frac_{Lea}}{100} * EF_{N2O.i.l} * \left(\frac{44}{28}\right)$$

Where:

- $N_2O_{i.v\,(S,T)}$ is the indirect nitrous oxide emissions from volatilization of NH_3 and NO from manure management S per animal type T (kg $year^{-1}$);
- $N_{E\,(T)}$ is the nitrogen excretion per animal type T (kg $year^{-1}$);
- $Frac_{GasM\,(S,T)}$ is the fraction of Nitrogen that volatilizes in the form of NH_3 and NO from manure management S per animal type T (%). See Table 5;
- $EF_{N2O.i.v}$ is emission factor 0.01 kg N2O-N/kg NH3-N and NOx-N. (based on IPCC (2006a)Table 10.21);
- the factor 44/28 is to convert mass of N_2O-N to mass of N_2O;
- $N_2O_{i.l\,(S,T)}$ is the indirect nitrous oxide emissions from leaching NO_3^- from manure management S per animal type T (kg $year^{-1}$);
- $Frac_{Leach\,(S)}$ is the fraction of Nitrogen that leach in the form of NO_3^-: 10% (based on typical range of 1-20% indicated inIPCC (2006a));
- $EF_{N2O.i.l}$ is the emission factor 0.0075 kg N2O-N/kg NO_3^- (based on IPCC (2006a) Table 10.21).

TABLE 5 FRACTION OF NH3 AND NOX RELEASED FROM VARIOUS MANAGEMENT SYSTEMS FROM IPCC (2006A).

Animal	Manure management system	$FRAC_{GASM}$ (kg NH_3-N and NO_x-N/kg N excreted)
Dairy cow	Anaerobic Lagoon	35% (20 – 80)
	Liquid/Slurry	40% (15 – 45)
	Pit Storage	28% (10 – 40)
	Dry Lot	20% (10 – 35)
	Solid storage	30% (10 – 40)
	Daily spread	7% (5 – 60)
Other cattle	Dry lot	30% (20 – 50)
	Solid storage	45% (10 – 65)
	Deep bedding	30% (20 – 40)

4.7 NH_3 emissions (from manure management)

4.7.1 Baseline: PEFCR Dairy 2018 - EMEP/ EEA Tier 2

NH_3 emissions are calculated according to EMEP/EEA (2016). This means that the emissions of NH3 released to the air are calculated differently than the NH_3 emissions calculated for indirect N_2O emissions estimation (Table 5).

$$NH_3 = TAN_{E\,(T)} * EF_{NH3\,(T,S)} * \left(\frac{17}{14}\right)$$

Where:

- NH_3 is the emission of ammonia (kg-NH_3 $year^{-1}$);
- TAN_E is the daily excretion of TAN per animal type T (chapter 4.1.2);

- $EF_{NH\ (T,S)}$ is the emission factor for ammonia per animal type T and manure management system S (kg-NH_3-N kg-TAN^{-1}) (Table 6);
- the factor 17/14 is to convert mass of NH_3-N to mass of NH_3.

The model by EMEP/EEA (2016) contains the following steps:

- First, the TAN released on housing, yard and grazing are estimated based on the time spent on these locations by the animal type T.
- Second, the emissions at housing, yard and grazing are calculated based on the $EF_{NH3\ (T,S)}$. The fraction of liquid/solid are consider for housing emissions (Table 7).
- Only for housing, the remaining nitrogen that is stored is multiplied by the storage emission factor (defined by the user).
- Manure after storage and after open yard is then spread on the field (accounted for in cultivation background LCI).

A more extensive overview over the steps can be found paragraph 3.4 of EMEP/EEA (2016).

TABLE 6 EMEP/EEA EMISSION FACTOR DEFAULTS FOR AMMONIA VOLATILIZATION.

Animal type	Manure type	$EF_{NH3\ (T,S)}$ (kg-NH_3-N kg-TAN^{-1})			
		EF housing	EF storage	EF yard	EF grazing
Dairy cattle	Slurry	0.20	0.22	0.30	0.10
	Solid	0.19	0.27	0.30	0.10
Non-dairy cattle	Slurry	0. 20	0.20	0.53	0.06
	Solid	0.19	0.27	0.53	0.06

For storage, the unit is kg-NH3-N kg-TAN^{-1} remaining.

TABLE 7 LIQUID/SOLID FRACTION OF MANURE MANAGEMENT SYSTEM IN DAIRY APS MODULE.

Manure management system in housing	Solid	Slurry
Daily spread	0%	100%
Solid storage	100%	0%
Dry lot	100%	0%
Liquid/Slurry	0%	100%
Anaerobic lagoon	0%	100%
Pit storage below animal confinement	50%	50%
Cattle and Swine deep bedding	100%	0%

4.8 Other N-related emissions (from manure management)

4.8.1 Baseline: PEFCR Dairy 2018 - EMEP/ EEA Tier 2

EMEP/EEA (2016) is used for proportion of TAN emitted as NO (0.0001 if slurry, 0.01 if solid) and as N_2 (0.003 if slurry, 0.3 if solid).

4.9 Non-Methane Volatile Organic Compound (NMVOC) emissions

4.9.1 Baseline: PEFCR Dairy 2018 - EMEP/ EEA Tier 2

In EMEP/EEA (2016) distinction is made between on housing emissions from silage feeding (0.202 g NMVOC/MJ GE for cattle) and from other type of feed (0.0353202 g NMVOC/MJ GE for cattle) (defined by the user). Emissions at open yard EF is 0.0069 g NMVOC/MJ GE for cattle.

4.10 Particulate Matter (PM) emissions

4.10.1 Baseline: PEFCR Dairy 2018 - EMEP/ EAA Tier 1

Tier 1 default from EMEP/EEA (2016) are:

TABLE 8 PARTICULATE MATTER TIER 1 EMISSION FACTOR FROM EMEP/EEA. THE VALUES ARE LITERATURE BASED (SEE TABLE 3.5 IN EMEP/EEA (2016)). TSP STANDS FOR TOTAL SUSPENDED PARTICLES.

Animal type	Tier 1: EF_{PM}		
	EF_{TSP} (kg TSP/AAP/year)	EF_{PM10} (kg PM_{10}/AAP/year)	$EF_{PM2.5}$ (kg $PM_{2.5}$/AAP/year)
Dairy cattle	1.38	0.63	041
Calves	0.34	0.16	0.10
Other cattle	0.59	0.27	0.18

5. APS reference systems for dairy

Reference systems are implemented in APS-footprint to provide a default set of data for typical housing systems. A reference system can be used as a starting point of an analysis. It contains default data related to milk yield and other outputs, herd composition, feed, water, bedding and energy.

5.1 Reference system for the Netherlands

APS-footprint contains a reference system for dairy that is typical for the Netherlands. Most of the data are based on CBS statistics and Agrimatie (CBS, 2017; Wageningen UR, 2016). The typical Dutch farm is considered to have on-farm cultivation of maize for silage, grass for silage and grass for pasture.

The herd composition (in AAP) is as follows: dairy cows (103), heifers (5), calves from 1 to 2 years of age (31) and calves below 1 year of age (35). The amount of heifer was calculated based on a replacement rate of 27.1%, a mortality of 1.5% (expert judgment) and an average age of first calving of 788 days (CRV, 2019). Other data used for determining the AAP are heifer and calves 1-2 year mortalities of 1.5 % (expert judgment), calves from 1 month up to 1 year mortality of 5% and 9% mortality of calves younger than 1 month (CRV, 2019). Also, the amount of 64 sold calves was derived from Agrimatie (Wageningen UR, 2016). Milk yield per dairy cow is 8328 kg of raw milk every year. Other outputs of the system are liveweight of mature cows for slaughtering (17500 kg) and sold calves (3008 kg). These are based on a weight for dairy cow of 625 kg and 45 kg for sold calves (CBS, 2017).

The input of compound feed is based on CBS (2017) and the overall compound feed intake of the farm is expressed per dairy cow. Compound feed formulation based on Agri-Footprint methodology (Van Paassen et al., 2019a, 2019b).

The methodology for the Life Cycle Inventories for cultivation of grass, maize, silage, and other background processes (energy, fertilizers etc.) is described in Agri-Footprint methodology (Van Paassen et al., 2019a, 2019b).

The same Dutch reference system is also available with all the parameters rescaled to an overall average herd population of 100 animals.

The Dutch dairy reference system has been externally reviewed by Gerben Doornewaard from Wageningen Economic Research in February 2019.

TABLE 9: DUTCH DAIRY FARM PARAMETERS. ALL VALUES EXPRESSED ON A YEARLY BASIS.

Parameter	Unit	Value	Source
Average annual temperature	degrees Celsius	10	(Wikipedia, 2020)
Country		The Netherlands	
Milk protein content	%	3.51	(CBS, 2017)
Fat content	%	4.39	(Wageningen UR, 2016)

Parameter	Unit	Value				Source
Milk produced	kg	857784				(CBS, 2017)
Liveweight co-product	kg	20508				calculated
Water	kg	4302532				(Wageningen UR, 2017)
Electricity/NL	MJ	167359				(Reijs, Doornewaard, Jager, Hoogeveen, & Beldman, 2016)
Gas	MJ	41145				
Diesel	MJ	0				
Animal type - Housing		Dairy cows	Calves <1 year	Calves 1-2 year	Heifers	
Straw for bedding	kg animal^{-1}	250	0	0	0	(Wageningen UR, 2017)
Saw dust for bedding	kg animal^{-1}	125	0	0	0	(Wageningen UR, 2017)
Average annual population of animals	#	103	35	31	5	(Wageningen UR, 2016)
Manure management system type		Pit storage (> 1 month)	Pit storage (> 1 month)	Pit storage (> 1 month)	Pit storage (> 1 month)	Expert judgment
Percentage of manure stored on farm before spreading	%	50	50	50	50	Expert judgment
Feed intake	kg as is animal^{-1}	18288.44	3905.95	11221.67	11221.79	Calculated
Compound feed	kg as is animal^{-1}	2297	0	0	0	(CBS, 2017)
Milk powder	kg as is animal^{-1}	0	49.6	0	0	(Wageningen UR, 2017)
Grass grazed	kg as is animal^{-1}	5287.5	1540.55	7390.67	7390.67	(CBS, 2017): dairy cows. (CBS, 2010): other animals
Grass silage	kg as is animal^{-1}	5644.68	1893.6	3545.7	3545.8	
Maize silage	kg as is animal^{-1}	5059.26	422.2	285.3	285.3	
Digestibility	% of Gross Energy intake	70	80	70	70	(IPCC, 2006a)
Gross energy intake	MJ animal^{-1}	106835.5	23250.5	52268	52268	(Centraal Veevoeder Bureau, 2018)
Crude protein in diet	% of DM	17.6	19.3	20.4	20.4	
Percentage of silage in feed	% of Gross Energy intake	66.4	76.1	58.8	58.8	calculated
Percentage of time spent grazing	%	11.4	10.9	26	26	(CBS, 2017)
Percentage of time spent in housing	%	88.6	89.1	74	74	calculated
Percentage of time spent in open yard areas	%	0	0	0	0	Expert judgment

TABLE 10: DUTCH DAIRY COMPOUND FEED COMPOSITION FOR THE APS REFERENCE SYSTEM.

Dairy compound feed	g/kg
Wheat grain, dried	64.5
Wheat bran, from wet milling	10.8
Wheat gluten feed	37.6
Triticale grain, dried	26.9
Sugar beet pulp dried	48.4
Sugar cane molasses	11.0
Sugar beet molasses	32.0
Soybean hull (solvent)	16.1
Soybean meal (solvent)	118.3
Rapeseed meal (solvent)	182.8
Palm kernel expeller	145.2
Maize	193.5
Maize gluten meal dried	10.8
Citrus pulp dried	91.4
Barley grain, dried	10.8

5.2 Reference system for California

APS-footprint also contains a reference system for dairy that is typical for California. California was chosen since large producer in US and because data are easier to retrieve. Most of the data are based on the US NIR (EPA, 2018), California Dairy Statistics (CDFA, 2016) and Thoma et al. (2012) . The typical farm described is consider the absence of pasture and open yards. Land is dedicated to roughages cultivations (corn silage, alfalfa) and grain (oat, wheat).

The herd composition is as follows: dairy cows (100), heifers (10), calves from 1 to 2 years of age (41) and calves below 1 year of age (44). The mortality rates are all based on GLEAM (2017): 4% for dairy cows, 0.4% for heifers, 1.6% for calves from 1 to 2 years of age and 6.4% for calves below 1 year of age. Milk yield per dairy cow is 10426 kg of raw milk every year. Other outputs of the system are culled cow (21080 kg based on a weight of 680 kg (EPA, 2018), a 31% replacement rate and mortality of 4% (GLEAM, 2017)) and sold calves (2880 kg based on 64 calves sold with an assumed weight of 45 kg).

The feed intake and consequential N excretion of heifers also includes the feed fed to youngstock.

The Life Cycle Inventories for cultivation of grass, maize, silages, hays, and other background processes (energy, fertilizers etc.) can be consulted in Agri-Footprint methodology (Van Paassen et al., 2019a, 2019b).

Another reference is also available for US-California system with all the parameters are rescaled to an overall herd population of 100 animals.

The Californian reference system has not been externally reviewed.

TABLE 11: CALIFORNIAN DAIRY FARM PARAMETERS. ALL VALUES EXPRESSED ON A YEARLY BASIS.

Parameter	Unit					Source
Average annual temperature	degrees Celsius	16				(Wikipedia, 2020)
Country		US -California				
Milk protein content	%	3.42				(EPA, 2018)
Fat content	%	3.79				(CDFA, 2016)
Milk produced	kg	1041811				(CDFA, 2016)
Liveweight co-product	kg	23960				calculated
Water	kg	4177215				Based on NL data: (Wageningen UR, 2017)
Electricity	MJ	217530				(Thoma et al., 2012)
Gas	MJ	0				
Diesel	MJ	0				
Animal type - Housing		Dairy cows	Calves <1 year	Calves 1-2 year	Heifers	
Straw for bedding	kg animal^{-1}	250	0	0	0	Based on NL data: (Wageningen UR, 2017)
Saw dust for bedding	kg animal^{-1}	125	0	0	0	
Average annual population of animals	#	100	44	41	10	(Thoma et al., 2013)
Manure management system type		Anaerobic Lagoon	Dry Lot	Dry Lot	Dry Lot	(IPCC, 2006a)
Percentage of manure stored on farm before spreading	%	50	50	50	50	Expert judgment
Feed intake	kg as is animal^{-1}	16124.82	0	0	58528.12	Calculated
Compound feed	kg as is animal^{-1}	3738.1	0	0	7098.59	(Thoma et al., 2013)
Straight feed corn	kg as is animal^{-1}	909.2	0	0	1194.08	
Grass	kg as is animal^{-1}	3569.04	0	0	177190.7	
Silage mix	kg as is animal^{-1}	6188.86	0	0	25322.27	
Hay mix	kg as is animal^{-1}	1459.33	0	0	4314.09	
Straw mix	kg as is animal^{-1}	260.29	0	0	2880.02	
Digestibility	% of GE	69	0	0	66	(Mangino et al., 2003)
Gross energy intake	MJ animal^{-1}	144868.5	0	0	414567	(Centraal Veevoeder Bureau, 2018)
Crude protein in diet	% of DM	17.4	0	0	15.4	
Percentage of silage in feed	% of GE	27	0	0	27	calculated
Percentage of time spent grazing	%	0	1	0	0	(EPA, 2018)
Percentage of time spent in housing	%	100	99	100	100	(EPA, 2018)
Percentage of time spent in open yard areas	%	0	0	0	0	(EPA, 2018)

TABLE 12: CALIFORNIAN DAIRY COMPOUND FEED COMPOSITION FOR THE APS REFERENCE SYSTEM (THOMA ET AL., 2013).

Feed composition dairy cows			**Feed composition heifers**		
Compound feed dairy cows	373.810	kg	Compound feed heifers	68.856	kg
Silage mix dairy cows	618.886	kg	Silage mix heifers	245.626	kg
Hay mix dairy cows	145.933	kg	Hay mix heifers	41.847	kg
Straw mix dairy cows	26.029	kg	Straw mix heifers	27.936	kg
Corn dairy cows	90.920	kg	Corn heifers	11.583	kg
Grass cows	356.904	kg	Grass heifers	171.875	kg
Compound feed dairy cows			**Compound feed heifers**		
Distillers grain, dry	17%		almond hulls	27%	
almond hulls	17%		Distillers grain, dry	20%	
canola meal	15%		canola meal	17%	
grain mix	12%		citrus pulp	10%	
corn gluten feed	7%		grain mix	9%	
cottonseed	6%		corn gluten feed, wet	3%	
wheat mill run	5%		molasses	3%	
barley	4%		soybean meal	3%	
citrus pulp	3%		protein mix	2%	
soybean meal	3%		corn gluten feed	2%	
corn, hominy	3%		wheat mill run	1%	
ddg, wet	3%		beet pulp	1%	
soy hulls	2%		cottonseed	1%	
molasses	1%		ddg, wet	1%	
corn gluten feed, wet	1%		fat	0%	
fat	1%				
beet pulp	0%				
protein mix	0%				
Silage mix dairy cows			**Silage mix heifers**		
corn silage	78%		corn silage	46%	
alfalfa silage	10%		alfalfa silage	5%	
grain silage	10%		grain silage	49%	
grass silage	3%		grass silage	1%	
Hay mix dairy cows			**Hay mix heifers**		
alfalfa hay	98%		alfalfa hay	95%	
grass hay	2%		grass hay	5%	
Straw mix dairy cows			**Straw mix heifers**		
wheat straw	27%		wheat straw	54%	
oat straw	57%		oat straw	46%	
corn, hm (stems)	16%				

Appendix I

TABLE 13 UNIT PROCESS CONNECTION IN THE CURRENT DEFAULT IMPLEMENTATION OF AGRI-FOOTPRINT DATABASE.

Input	Input process
Electricity, European countries	Electricity mix, AC, consumption mix, at consumer, < 1kV REGION S System - Copied from ELCD
Electricity, non-European countries	Electricity mix, AC, consumption mix, at consumer, < 1kV/REGION Economic
Gas, European countries	Process steam from natural gas, heat plant, consumption mix, at plant, MJ, REGION S System - Copied from ELCD
Gas, non-European countries	Process steam from natural gas, heat plant, consumption mix, at plant, MJ, EU-27 S System - Copied from ELCD
Diesel	Energy, from diesel burned in machinery/RER Economic
Water	Drinking water, water purification treatment, production mix, at plant, from groundwater RER S System - Copied from ELCD
Straw for bedding	Wheat straw, at farm/REGION Economic
Saw dust	Saw dust, wet, measured as dry mass {GLO}| market for | APOS, S - Copied from Ecoinvent
Sea ship	Transport, sea ship, 80000 DWT, 80%LF, middle, default/GLO Economic
Truck	Transport, truck >20t, EURO4, 80%LF, default/GLO Economic
Train	Transport, freight train, electricity, bulk, 50%LF, flat terrain, default/GLO Economic
Inland ship	Transport, barge ship, bulk, 5500t, 80%LF, default/GLO Economic
Fat from animals	Fat from animals, at processing/REGION Economic
Animal meal	Animal meal, at processing/REGION Economic
ValAMINO®, 98.0% L-Valine	ValAMINO®, 98.0% L-Valine, at Evonik plant/SK
TrypAMINO®, 98.0% L-Tryptophan	TrypAMINO®, 98.0% L-Tryptophan, at Evonik plant/SK
ThreAMINO®, 98.5% L-Threonine	ThreAMINO®, 98.5% L-Threonine, at Evonik plant/HU
MetAMINO®, 99% DL-Methionine	MetAMINO®, 99% DL-Methionine, at Evonik plant/BE
Biolys®, 54.6% L-Lysine	Biolys®, 54.6% L-Lysine, at Evonik plant/US
Whey powder dried	Whey powder dried, at processing/REGION Economic
Wheat grain, winter, dried	Wheat grain, winter, dried, at farm/REGION Economic
Wheat straw, winter	Wheat straw, winter, at farm/REGION Economic
Wheat grain, spring, dried	Wheat grain, spring, dried, at farm/REGION Economic
Wheat straw, spring	Wheat straw, spring, at farm/REGION Economic
Wheat grain, durum, dried	Wheat grain, durum, dried, at farm/REGION Economic
Wheat straw, durum	Wheat straw, durum, at farm/REGION Economic
Wheat grain, dried	Wheat grain, dried, at farm/REGION Economic
Wheat straw	Wheat straw, at farm/REGION Economic
Wheat gluten meal	Wheat gluten meal, at processing/REGION Economic
Wheat gluten feed	Wheat gluten feed, at processing/REGION Economic
Wheat bran, from wet milling	Wheat bran, from wet milling, at processing/REGION Economic
Wheat starch	Wheat starch, at processing/REGION Economic
Wheat bran, from dry milling	Wheat bran, from dry milling, at processing/REGION Economic
Wheat middlings & feed	Wheat middlings & feed, at processing/REGION Economic
Wheat germ	Wheat germ, at processing/REGION Economic
Wheat flour	Wheat flour, at processing/REGION Economic
Vinasse dried, at plant	Vinasse dried, at plant/REGION Economic
Triticale grain, dried	Triticale grain, dried, at farm/REGION Economic
Triticale straw	Triticale straw, at farm/REGION Economic
Dairy cow co-product, feed grade	Dairy cow co-product, feed grade, at slaughterhouse/REGION Economic
Groundnut meal	Groundnut meal, at processing/REGION Economic
Crude peanut oil	Crude peanut oil, at processing/REGION Economic
Crude palm oil	Crude palm oil, at processing/REGION Economic

Sunflower seed	Sunflower seed, at farm/REGION Economic
Sunflower hull (solvent)	Sunflower hull (solvent), at processing/REGION Economic
Sunflower seed meal (solvent)	Sunflower seed meal (solvent), at processing/REGION Economic
Crude sunflower oil (solvent)	Crude sunflower oil (solvent), at processing/REGION Economic
Sunflower hull (pressing)	Sunflower hull (pressing), at processing/REGION Economic
Sunflower seed expelled dehulled (pressing)	Sunflower seed expelled dehulled (pressing), at processing/REGION Economic
Crude sunflower oil (pressing)	Crude sunflower oil (pressing), at processing/REGION Economic
Sunflower hull (partial)	Sunflower hull (partial), at processing/REGION Economic
Sunflower seed dehulled (partial)	Sunflower seed dehulled (partial), at processing/REGION Economic
Sunflower hull (full)	Sunflower hull (full), at processing/REGION Economic
Sunflower seed dehulled (full)	Sunflower seed dehulled (full), at processing/REGION Economic
Sugar cane	Sugar cane, at farm/REGION Economic
Sugar cane molasses	Sugar cane molasses, at processing/REGION Economic
Sugar, from sugar cane	Sugar, from sugar cane, at processing/REGION Economic
Sugar beet	Sugar beet, at farm/REGION Economic
Sugar beet molasses	Sugar beet molasses, at processing/REGION Economic
Sugar beet pulp wet	Sugar beet pulp wet, at processing/REGION Economic
Sugar, from sugar beet	Sugar, from sugar beet, at processing/REGION Economic
Sugar beet pulp dried	Sugar beet pulp dried, at processing/REGION Economic
Soybean, heat treated	Soybean, heat treated, at processing/REGION Economic
Soybean	Soybean, at farm/REGION Economic
Soybean straw	Soybean straw, at farm/REGION Economic
Soybeans	Soybeans, at farm/REGION Economic
Soybean protein-isolate	Soybean protein-isolate, at processing/REGION Economic
Soybean okara	Soybean okara, at processing/REGION Economic
Soybean meal (solvent)	Soybean meal (solvent), at processing/REGION Economic
Crude soybean oil (solvent)	Crude soybean oil (solvent), at processing/REGION Economic
Soybean lecithin (solvent)	Soybean lecithin (solvent), at processing/REGION Economic
Soap stock (soybean) (solvent)	Soap stock (soybean) (solvent), at processing/REGION Economic
Refined soybean oil (solvent)	Refined soybean oil (solvent), at processing/REGION Economic
Soybean lecithin (pressing)	Soybean lecithin (pressing), at processing/REGION Economic
Soap stock (soybean) (pressing)	Soap stock (soybean) (pressing), at processing/REGION Economic
Refined soybean oil (pressing)	Refined soybean oil (pressing), at processing/REGION Economic
Soybean hull (solvent)	Soybean hull (solvent), at processing/REGION Economic
Soybean molasses	Soybean molasses, at processing/REGION Economic
Soybean fines	Soybean fines, at processing/REGION Economic
Soybean protein-concentrate	Soybean protein-concentrate, at processing/REGION Economic
Soybean expeller (pressing)	Soybean expeller (pressing), at processing/REGION Economic
Crude soybean oil (pressing)	Crude soybean oil (pressing), at processing/REGION Economic
Sorghum straw	Sorghum straw, at farm/REGION Economic
Sorghum grain	Sorghum grain, at farm/REGION Economic
Cottonseed	Cottonseed, at farm/REGION Economic
Soap stock (sunflower) (solvent)	Soap stock (sunflower) (solvent), at processing/REGION Economic
Refined sunflower oil (solvent)	Refined sunflower oil (solvent), at processing/REGION Economic
Soap stock (sunflower) (pressing)	Soap stock (sunflower) (pressing), at processing/REGION Economic
Refined sunflower oil (pressing)	Refined sunflower oil (pressing), at processing/REGION Economic
Soap stock (rice bran)	Soap stock (rice bran), at processing/REGION Economic
Refined rice bran oil	Refined rice bran oil, at processing/REGION Economic

Soap stock (rapeseed) (solvent)	Soap stock (rapeseed) (solvent), at processing/REGION Economic
Refined rapeseed oil (solvent)	Refined rapeseed oil (solvent), at processing/REGION Economic
Soap stock (rapeseed) (pressing)	Soap stock (rapeseed) (pressing), at processing/REGION Economic
Refined rapeseed oil (pressing)	Refined rapeseed oil (pressing), at processing/REGION Economic
Soap stock (palm kernel)	Soap stock (palm kernel), at processing/REGION Economic
Refined palm kernel oil	Refined palm kernel oil, at processing/REGION Economic
Soap stock (maize germ) (solvent)	Soap stock (maize germ) (solvent), at processing/REGION Economic
Refined maize germ oil (solvent)	Refined maize germ oil (solvent), at processing/REGION Economic
Soap stock (maize germ) (pressing)	Soap stock (maize germ) (pressing), at processing/REGION Economic
Refined maize germ oil (pressing)	Refined maize germ oil (pressing), at processing/REGION Economic
Soap stock (coconut)	Soap stock (coconut), at processing/REGION Economic
Refined coconut oil	Refined coconut oil, at processing/REGION Economic
Sesame seed	Sesame seed, at farm/REGION Economic
Rye middlings	Rye middlings, at processing/REGION Economic
Rye flour	Rye flour, at processing/REGION Economic
Rye grain, dried	Rye grain, dried, at farm/REGION Economic
Rye straw	Rye straw, at farm/REGION Economic
Rice	Rice, at farm/REGION Economic
Rice straw	Rice straw, at farm/REGION Economic
Rice husk meal (raw)	Rice husk meal (raw), at processing/REGION Economic
Rice husk meal (parboiled)	Rice husk meal (parboiled), at processing/REGION Economic
Rice husk meal (mixed)	Rice husk meal (mixed), at processing/REGION Economic
Rice husk (mixed)	Rice husk (mixed), at processing/REGION Economic
Rice feed meal	Rice feed meal, at processing/REGION Economic
Rice brokens (mixed)	Rice brokens (mixed), at processing/REGION Economic
Rice bran meal	Rice bran meal, at processing/REGION Economic
Crude rice bran oil	Crude rice bran oil, at processing/REGION Economic
Rice brokens (raw)	Rice brokens (raw), at processing/REGION Economic
Rice husk (raw)	Rice husk (raw), at processing/REGION Economic
Rice bran (raw)	Rice bran (raw), at processing/REGION Economic
Rice brokens (parboiled)	Rice brokens (parboiled), at processing/REGION Economic
Rice husk (parboiled)	Rice husk (parboiled), at processing/REGION Economic
Rice bran (parboiled)	Rice bran (parboiled), at processing/REGION Economic
Rice bran (mixed)	Rice bran (mixed), at processing/REGION Economic
Soap stock (linseed) (solvent)	Soap stock (linseed) (solvent), at processing/REGION Economic
Refined linseed oil (solvent)	Refined linseed oil (solvent), at processing/REGION Economic
Rapeseed, dried	Rapeseed, dried, at farm/REGION Economic
Rapeseed straw	Rapeseed straw, at farm/REGION Economic
Rapeseed meal (solvent)	Rapeseed meal (solvent), at processing/REGION Economic
Crude rapeseed oil (solvent)	Crude rapeseed oil (solvent), at processing/REGION Economic
Rapeseed expeller (pressing)	Rapeseed expeller (pressing), at processing/REGION Economic
Crude rapeseed oil (pressing)	Crude rapeseed oil (pressing), at processing/REGION Economic
Potatoes	Potatoes, at farm/REGION Economic
Potato pulp dried	Potato pulp dried, at processing/REGION Economic
Potato starch dried	Potato starch dried, at processing/REGION Economic
Potato pulp pressed fresh+silage	Potato pulp pressed fresh+silage, at processing/REGION Economic
Potato juice concentrated	Potato juice concentrated, at processing/REGION Economic
Potato protein	Potato protein, at processing/REGION Economic

Pigeon peas straw	Pigeon peas straw, at farm/REGION Economic
Pigeon peas	Pigeon peas, at farm/REGION Economic
Peas, dry straw	Peas, dry straw, at farm/REGION Economic
Peas, dry	Peas, dry, at farm/REGION Economic
Pea starch-concentrate	Pea starch-concentrate, at processing/REGION Economic
Pea protein-concentrate	Pea protein-concentrate, at processing/REGION Economic
Pea wet animal feed	Pea wet animal feed, at processing/REGION Economic
Pea starch slurry	Pea starch slurry, at processing/REGION Economic
Pea slurry	Pea slurry, at processing/REGION Economic
Pea protein-isolate	Pea protein-isolate, at processing/REGION Economic
Palm kernel expeller	Palm kernel expeller, at processing/REGION Economic
Crude palm kernel oil	Crude palm kernel oil, at processing/REGION Economic
Oat mill feed meal high grade	Oat mill feed meal high grade, at processing/REGION Economic
Oat husk meal	Oat husk meal, at processing/REGION Economic
Oat grain peeled	Oat grain peeled, at processing/REGION Economic
Oat grain, dried	Oat grain, dried, at farm/REGION Economic
Oat straw	Oat straw, at farm/REGION Economic
Mustard seed	Mustard seed, at farm/REGION Economic
Milk powder (skimmed)	Milk powder (skimmed), at processing/REGION Economic
Milk powder (full fat)	Milk powder (full fat), at processing/REGION Economic
Maize	Maize, at farm/REGION Economic
Coconut copra meal	Coconut copra meal, at processing/REGION Economic
Crude coconut oil	Crude coconut oil, at processing/REGION Economic
Citrus pulp dried	Citrus pulp dried, at processing/REGION Economic
Chicory roots	Chicory roots, at farm/REGION Economic
Chick peas straw	Chick peas straw, at farm/REGION Economic
Chick peas	Chick peas, at farm/REGION Economic
Cassava	Cassava, at farm/REGION Economic
Cassava root, dried	Cassava root, dried, at farm/REGION Economic
Cassava peel (with use of co-products)	Cassava peel (with use of co-products), at processing/REGION Economic
Cassava pomace (fibrous residue) (with use of co-products)	Cassava pomace (fibrous residue) (with use of co-products), at processing/REGION Economic
Tapioca starch (with use of co-products)	Tapioca starch (with use of co-products), at processing/REGION Economic
Broad beans, horse beans, dry straw	Broad beans, horse beans, dry straw, at farm/REGION Economic
Broad beans	Broad beans, at farm/REGION Economic
Broad bean hull	Broad bean hull, at processing/REGION Economic
Broad bean meal	Broad bean meal, at processing/REGION Economic
Brewer's grains	Brewer's grains, at processing/REGION Economic
Beef co-product, feed grade	Beef co-product, feed grade, at slaughterhouse/REGION Economic
Beans, dry straw	Beans, dry straw, at farm/REGION Economic
Beans, dry	Beans, dry, at farm/REGION Economic
Barley grain, dried	Barley grain, dried, at farm/REGION Economic
Barley straw	Barley straw, at farm/REGION Economic
Maize starch dried	Maize starch dried, at processing/REGION Economic
Maize middlings	Maize middlings, at processing/REGION Economic
Maize flour	Maize flour, at processing/REGION Economic
Maize gluten meal dried	Maize gluten meal dried, at processing/REGION Economic
Maize gluten feed dried	Maize gluten feed dried, at processing/REGION Economic

Maize germ meal extracted (solvent)	Maize germ meal extracted (solvent), at processing/REGION Economic
Crude maize germ oil (solvent)	Crude maize germ oil (solvent), at processing/REGION Economic
Maize germ meal expeller (pressing)	Maize germ meal expeller (pressing), at processing/REGION Economic
Crude maize germ oil (pressing)	Crude maize germ oil (pressing), at processing/REGION Economic
Maize germ dried	Maize germ dried, at processing/REGION Economic
Maize fibre/bran	Maize fibre/bran wet, at processing/REGION Economic
Maize distillers grains dried, at plant	Maize distillers grains dried, at plant/REGION Economic
Maize bran	Maize bran, at processing/REGION Economic
Lupins straw	Lupins straw, at farm/REGION Economic
Lupins	Lupins, at farm/REGION Economic
Lupins protein-isolate	Lupins protein-isolate, at processing/REGION Economic
Lupins oil	Lupins oil, at processing/REGION Economic
Lupins okara	Lupins okara, at processing/REGION Economic
Lupins hull (protein-isolate)	Lupins hull (protein-isolate), at processing/REGION Economic
Lupins protein slurry	Lupins protein slurry, at processing/REGION Economic
Lupins hull (meal)	Lupins hull (meal), at processing/REGION Economic
Lupins meal	Lupins meal, at processing/REGION Economic
Lupins fibre	Lupins fibre, at processing/REGION Economic
Lupins hull (protein-concentrate)	Lupins hull (protein-concentrate), at processing/REGION Economic
Lupins protein-concentrate	Lupins protein-concentrate, at processing/REGION Economic
Lucerne, dried	Lucerne, dried, at farm/REGION Economic
Liquid whey (Gouda 48+)	Liquid whey (Gouda 48+), at processing/REGION Economic
Linseed straw	Linseed straw, at farm/REGION Economic
Linseed	Linseed, at farm/REGION Economic
Linseed meal (solvent)	Linseed meal (solvent), at processing/REGION Economic
Crude linseed oil (solvent)	Crude linseed oil (solvent), at processing/REGION Economic
Linseed expeller (pressing)	Linseed expeller (pressing), at processing/REGION Economic
Crude linseed oil (pressing)	Crude linseed oil (pressing), at processing/REGION Economic
Lentils straw	Lentils straw, at farm/REGION Economic
Lentils	Lentils, at farm/REGION Economic
Fodder beet (fresh)	Fodder beet (fresh), at processing/REGION Economic
Fish meal	Fish meal, at processing/REGION Economic
Fish oil	Fish oil, at processing/REGION Economic
Fatty acid distillates (palm oil)	Fatty acid distillates (palm oil), at processing/REGION Economic
Refined palm oil	Refined palm oil, at processing/REGION Economic
Vinasse wet (sugar cane), at plant	Vinasse wet (sugar cane), at plant/REGION Economic
Limestone	Crushed stone 16/32 mm, open pit mining, production mix, at plant, undried RER S System - Copied from ELCD
Phosphate	Phosphate rock (32% P2O5, 50% CaO) (NPK 0-32-0), at mine/REGION Economic
Salt	Sodium chloride, production mix, at plant, dissolved RER System - Copied from ELCD
staight feed corn, dairy cow, usa	Straight feeds 3 corn dairy cows, Dairy, Country average/US
hay mix for dairy cows, grown on farm, USA	Feed grown on farm 3, hay mix dairy cows, Dairy, Country average/US
hay mix for heifers, grown on farm, USA	Feed grown on farm 4 hay mix heifers, Dairy, Country average/US
silage mix for heifers, grown on farm, USA	Feed grown on farm 2, silage mix heifers, Dairy, Country average/US
silage mix for dairy cows, grown on farm, USA	Feed grown on farm 1, silage mix dairy cows, Dairy, Country average/US
Straight feed corn, heifers, USA	Straight feeds 4 corn heifers, Dairy, Country average/US
straw mix, heifers - USA	Straight feeds 2, straw mix heifers, Dairy, Country average/US
straw mix, dairy cows - USA	Straight feeds 1, straw mix dairy cows, Dairy, Country average/US

Grass for grazing, permanent pasture, NL	Grass BEAST, at dairy farm/NL Economic
Grass silage, grown on farm, NL	Feed grown on farm 1, grass silage, Dairy, Country average/NL
Maize silage, grown on farm, NL	Feed grown on farm 2, maize silage, Dairy, Country average/NL
Wheat starch, purchased, NL	Wheat starch, at processing/NL Economic
Brewer's grains	Brewer's grains, consumption mix, at feed compound plant/NL Economic
Maize solubles, purchased, NL	Maize solubles, at processing/NL Economic
Maize solubles, purchased, US	Maize solubles, at processing/US Economic
Potato pulp pressed, purchased, NL	Potato pulp pressed fresh+silage, at processing/NL Economic
Potato starch dried, purchased, NL	Potato starch dried, consumption mix, at feed compound plant/NL Economic
Sugarbeet pulp dried, purchased, NL	Sugar beet pulp dried, at processing/NL Economic
Wheat grain, grown on farm, NL	Wheat grain, at farm/NL Economic
Wheat grain, purchased, NL	Wheat grain, market mix, at regional storage/NL Economic
Wheat grain, grown on farm, US	Wheat grain, production mix, at farm/US Economic
Wheat grain, purchased, US	Wheat grain, market mix, at regional storage/US Economic
Barley grain, grown on farm, NL	Barley grain, at farm/NL Economic
Barley grain, purchased, NL	Barley grain, market mix, at regional storage/NL Economic
Barley grain, grown on farm, US	Barley grain, at farm/US Economic
Barley grain, purchased, US	Barley grain, market mix, at regional storage/US Economic
Maize, grown on farm, NL	Maize, at farm/NL Economic
Maize, purchased, NL	Maize, market mix, at regional storage/NL Economic
Maize, grown on farm, US	Maize, production mix, at farm/US Economic
Maize, purchased, US	Maize, market mix, at regional storage/US Economic
Rye grain, grown on farm, NL	Rye grain, at farm/NL Economic
Rye grain, purchased, NL	Rye grain, market mix, at regional storage/NL Economic
Rye grain, grown on farm, US	Rye grain, at farm/US Economic
Rye grain, purchased, US	Rye grain, market mix, at regional storage/US Economic
Oat grain, grown on farm, NL	Oat grain, at farm/NL Economic
Oat grain, purchased, NL	Oat grain, market mix, at regional storage/NL Economic
Oat grain, grown on farm, US	Oat grain, production mix, at farm/US Economic
Oat grain, purchased, US	Oat grain, market mix, at regional storage/US Economic
Triticale grain, grown on farm, NL	Triticale grain, at farm/NL Economic
Triticale grain, purchased, NL	Triticale grain, market mix, at regional storage/NL Economic
Wheat bran (dry milling), purchased, NL	Wheat bran, from dry milling, at processing/NL Economic
Wheat bran (wet milling), purchased, NL	Wheat bran, from wet milling, at processing/NL Economic
Maize distillers grains wet, purchased, US	Maize distillers grains wet (maize), at plant/US Economic
Maize distillers grains dried, purchased, US	Maize distillers grains dried, at plant/US Economic
Maize gluten feed dried, purchased, NL	Maize gluten feed dried, at processing/NL Economic
Maize gluten feed dried, purchased, US	Maize gluten feed dried, at processing/US Economic
Maize gluten feed wet, purchased, NL	Maize gluten feed wet, at processing/NL Economic
Maize gluten feed wet, purchased, US	Maize gluten feed wet, at processing/US Economic
Sugarbeet molasses, purchased, NL	Sugar beet molasses, at processing/NL Economic
Sugarbeet molasses, purchased, US	Sugar beet molasses, at processing/US Economic
Soybean meal, purchased, NL	Soybean meal (solvent), market mix, at regional storage/NL Economic
Soybean meal, purchased, US	Soybean meal (solvent), market mix, at regional storage/US Economic
Soybean expeller, purchased, NL	Soybean expeller (pressing), market mix, at regional storage/NL Economic
Soybean expeller, purchased, US	Soybean expeller (pressing), market mix, at regional storage/US Economic
Rapeseed meal, purchased, NL	Rapeseed meal (solvent), market mix, at regional storage/NL Economic
Rapeseed meal, purchased, US	Rapeseed meal (solvent), market mix, at regional storage/US Economic

Rapeseed expeller, purchased, NL	Rapeseed expeller (pressing), market mix, at regional storage/NL Economic
Rapeseed expeller, purchased, US	Rapeseed expeller (pressing), market mix, at regional storage/US Economic
Sunflowerseed meal, purchased, NL	Sunflower seed meal (solvent), market mix, at regional storage/NL Economic
Sunflowerseed expeller (dehulled), purchased, NL	Sunflower seed expelled dehulled (pressing), market mix, at regional storage/NL Economic
Horse beans, purchased, NL	Broad bean, market mix, at regional storage/NL Economic
Lupins, purchased, NL	Lupine, consumption mix, at feed compound plant/NL Economic
Peas, grown on farm, NL	Peas, dry, at farm/NL Economic
Peas, purchased, NL	Peas, dry, market mix, at regional storage/NL Economic
Peas, grown on farm, US	Peas, dry, at farm/US Economic
Peas, purchased, US	Peas, dry, market mix, at regional storage/US Economic
Soybeans, purchased, NL	Soybeans, market mix, at regional storage/NL Economic
Soybeans, grown on farm, US	Soybean, production mix, at farm/US Economic
Soybeans, purchased, US	Soybeans, market mix, at regional storage/US Economic
Wheat straw, grown on farm, NL	Wheat straw, at farm/NL Economic
Wheat straw, grown on farm, US	Wheat straw, at farm/US Economic
Barley straw, grown on farm, NL	Barley straw, at farm/NL Economic
Barley straw, grown on farm, US	Barley straw, at farm/US Economic
Rye straw, grown on farm, NL	Rye straw, at farm/NL Economic
Rye straw, grown on farm, US	Rye straw, at farm/US Economic
Oat straw, grown on farm, NL	Oat straw, at farm/NL Economic
Oat straw, grown on farm, US	Oat straw, at farm/US Economic
Triticale straw, grown on farm, NL	Triticale straw, at farm/NL Economic
Bean straw (Phaseolus), grown on farm, NL	Beans, dry straw, at farm/NL Economic
Pea straw, grown on farm, NL	Peas, dry straw, at farm/NL Economic
Pea straw, grown on farm, US	Peas, dry straw, at farm/US Economic
Grass (dairy), grown on farm, NL	Grass, at dairy farm/NL Economic
Grass silage (dairy), grown on farm, NL	Grass silage (dairy), at farm/NL Economic
Fodder beet, grown on farm, NL	Fodder beet, at farm/NL Economic

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