Agri-footprint 5.0

Part 2: Description of data

DATE: 17-7-2019

agri›footprint‹

Agri-footprint is a high quality and comprehensive life cycle inventory (LCI) database, focused on the agriculture and food sector. It covers data on agricultural products: feed, food and biomass and is used by life cycle assessment (LCA) practitioners. In total the database contains approximately 11,000 products. In the last years Agri-footprint is widely accepted by the food industry, LCA community, scientific community and governments worldwide and has been critically reviewed.

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Table of Contents

1 Introduction ... 4

2 What's new? ... 6

2.1 Agri-footprint 5.0 ... 6

3 Cultivation of crops ... 7

3.1 Introduction and reader's guidance ... 7

3.2 Collected activity data ... 9

3.2.1 Yield ... 9

3.2.2 Irrigation water ... 10

3.2.3 Land occupation ... 10

3.2.4 Land use change ... 10

3.2.5 Nitrogen from manure ... 11

3.2.6 Inorganic fertilizer application rates ... 12

3.2.7 Capital goods ... 12

3.2.8 Lime ... 12

3.2.9 Seed input ... 12

3.2.10 Transport requirements ... 13

3.2.11 Pesticide input and emissions ... 13

3.2.12 Energy input ... 13

3.3 Modelled emissions ... 14

3.3.1 Nitrous oxide (N_2O) emissions ... 14

3.3.2 Ammonia (NH_3) and nitrate (NO_3^-) emissions – tier 1 ... 17

3.3.3 Carbon dioxide (CO_2) emissions ... 17

3.3.4 IPCC tier 1 emissions factors and constants ... 19

3.3.5 Nitric oxide (NO) emissions ... 20

3.3.6 Ammonia (NH_3) emissions – tier 2 ... 20

3.3.7 Phosphor emissions ... 20

3.3.8 Heavy metal emissions ... 21

3.3.9 Specific emissions ... 26

3.4 Integration of USDA LCA commons crop data in Agri-footprint ... 26

4 Processing of crops at post-harvest ... 27

4.1 Deshelling/dehusking ... 27

4.2 Drying ... 27

5 Market mixes of commodities ... 28

5.1 Market mix of raw materials ... 28

5.2 Market mix of processed materials ... 30

5.3 Transportation requirements for market mixes ... 31

5.3.1 Data collection 31
5.3.2 Transport of crops from cultivation areas to central hubs 31
6 Processing of crops and animal products into feed and food ingredients 32
6.1 Introduction and reader's guidance 32
6.1.1 Waste in processing 34
6.1.2 Water use in processing 34
6.1.3 Energy use in processing 35
6.1.4 Auxiliary material/other ingredients in processing 35
6.2 Animal products 35
6.2.1 Meat co-products 35
6.2.2 Fish co-products 35
6.2.3 Dairy products 35
6.3 Cereal products 36
6.3.1 Wet milling (maize, wheat) 36
6.3.2 Dry milling (maize, wheat, rye, oat) 37
6.3.3 Dry milling (rice) 37
6.4 Oilseed products 39
6.4.1 Crushing 39
6.4.2 Oil refining 40
6.5 Pulse products 41
6.5.1 Pulse protein-concentrates 42
6.5.2 Pulse protein isolates 43
6.6 Roots & tuber products 45
6.7 Sugar products 45
6.7.1 Sugar from sugar beet 45
6.7.2 Sugar from sugar cane 45
7 Animal farm systems 47
7.1 Dairy farm system in the Netherlands 47
7.2 Irish Beef 52
7.3 Pig production in the Netherlands 56
7.3.1 Production of humic acid 59
7.4 Poultry 60
7.4.1 Laying hens in the Netherlands 60
7.4.2 Broilers in the Netherlands 63
7.5 Slaughterhouse 67
8 Background processes 70
8.1 Extension of ELCD data 70
8.1.1 Electricity grids outside Europe 70

8.2 Transport processes 72
8.2.1 Road 72
8.2.2 Water 73
8.2.3 Rail 76
8.2.4 Air 77
8.3 Auxiliary materials 80
8.3.1 Bleaching earth 80
8.3.2 Sulfur dioxide 80
8.3.3 Sodium Hydroxide and Chlorine 81
8.3.4 Phosphoric Acid 85
8.3.5 Sulfuric Acid 85
8.3.6 Activated Carbon 86
8.3.7 Hexane 86
8.4 Fertilizers production 86
8.5 Nutramon® (NPK 27-0-0) from OCI nitrogen 94
8.6 Capital goods 96
8.6.1 Truck & Tractor production 96
8.7 Amino acids from Evonik 98
9 Data quality ratings 99
9.1 Data quality system and indicators 99
9.2 Data quality of agricultural processes 99
9.3 Data quality of processing agricultural products 102
References 103
List of tables and figures 110
List of tables 110
List of figures 113
Appendices 115

1 Introduction

The main objective of Agri-footprint is to bring data and methodology together to make it easily available for the LCA community.

This document contains background information on the methodology, calculation rules and data that are used for the development of the data published in the 5th release of Agri-footprint and on the website (www.agri-footprint.com). This document will be updated whenever new or updated data is included in Agri-footprint.

Agri-footprint is available as a library within SimaPro and OpenLCA. Information, FAQ, logs of updates and reports are publicly available via the website www.agri-footprint.com. Agri-footprint users can also ask questions via this website. The project team can also be contacted directly via info@agri-footprint.com , or the LinkedIn user group.

While part 1 of the report outlines the choices in methodology and general principles used in the development of the database, this document (part 2), outlines the sources of data and specific modelling choices for the development of the individual datasets.

The document is structured to cover the main groups of life cycle inventories in Agri-footprint. It follows a standard agricultural supply chain (Figure 1-1): the cultivation of crops (Chapter 3), the post-harvesting processing (Chapter 4), production and market mixes including transportation (Chapter 5), the processing of crops and animal products into food and feed (Chapter 6), and the animal systems, including also the feed compound processing and slaughtering of animals (Chapter 7). The last chapter cover the various background processes (Chapter 8).

Of course, the supply chain is not always so straightforward; there are indeed many loops, such as the co-products of animal slaughtering being processed into feed ingredients. Also, some supply chains omit one or more of the steps described (e.g. various crop do not have post-harvest processing or processing).

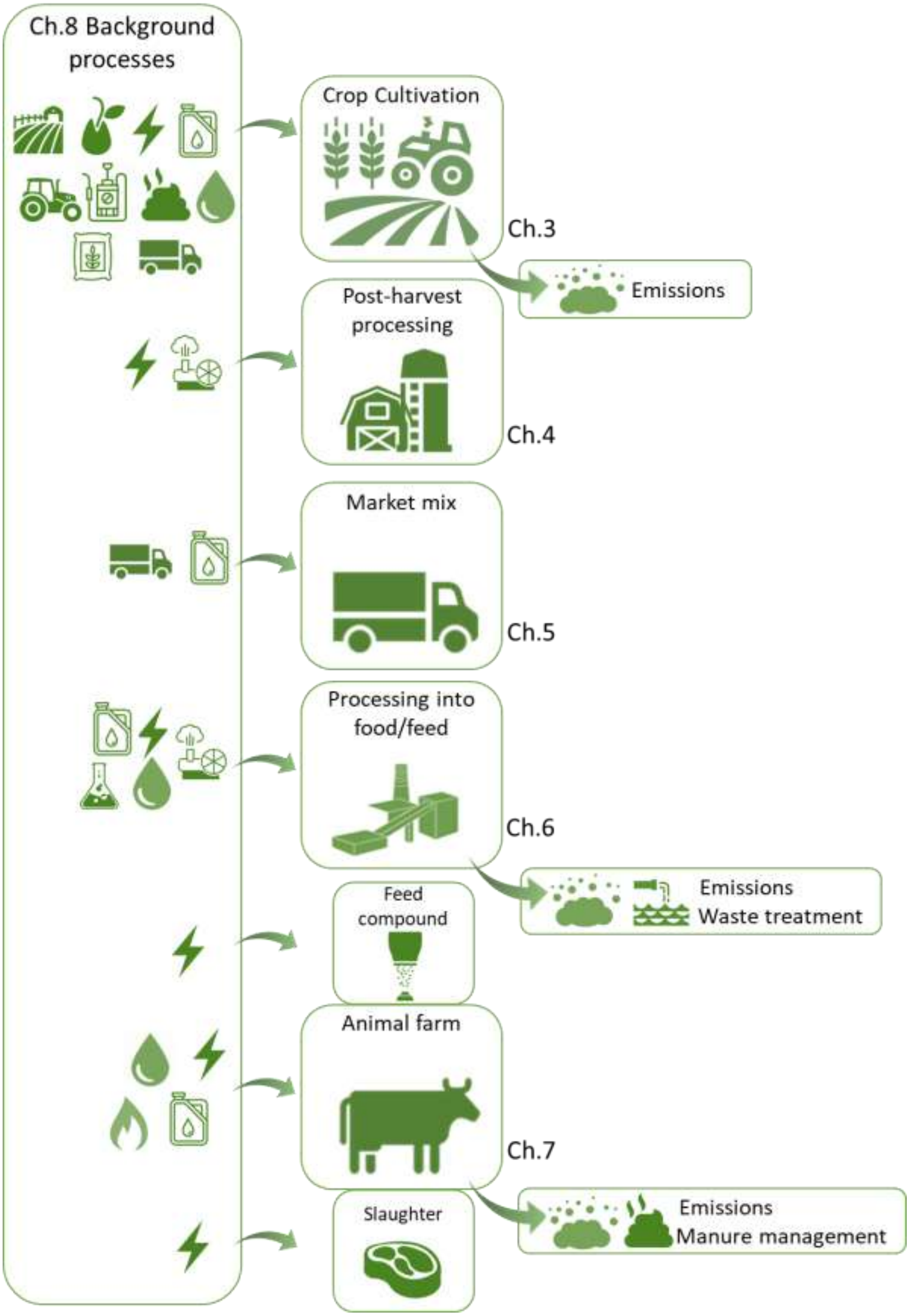


Figure 1-1 General agri-food supply chain representative of most Agri-footprint life-cycle stages. Indicated are also the chapter of reference for the data description.

2 What's new?

2.1 Agri-footprint 5.0

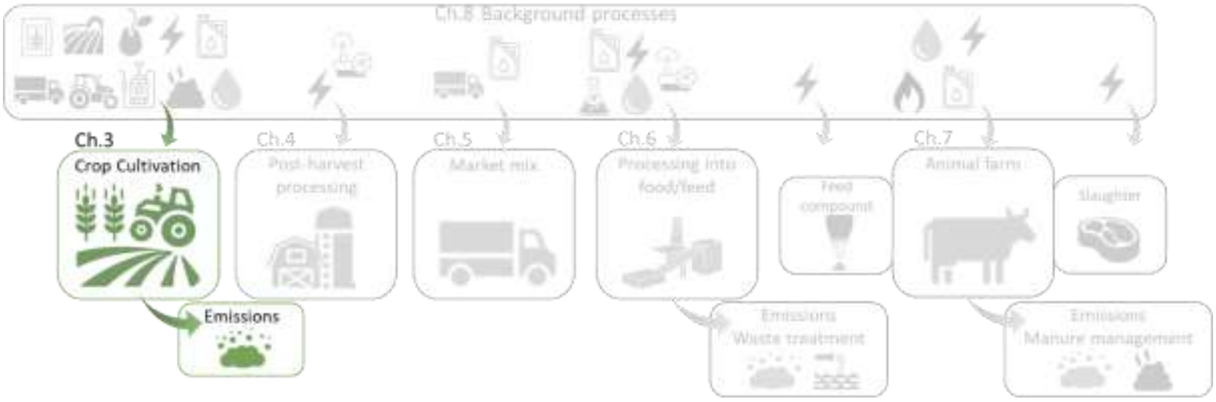
1. **Focus on more markets**: In addition to the Dutch feed market, there is now a stronger focus for feed materials in the European and American markets.
2. **Update on activity data for crop cultivation**: Next to an update of the source data, new models have been developed to quantity inputs and emissions in more detail and more consistently throughout the database. These include:
    a. Fertilizer model to estimate the NPK use using most recent industry data (section 3.2.6)
    b. Energy model to estimate energy demand for nine different on field agricultural activities using crop and country specific parameters (section 3.2.12)
    c. Pesticide model to estimate the amount of insecticide, fungicide and herbicides applied using most recent public data (section 3.2.11)
3. **Market mixes of processed materials**: using some 'logic' and trade data on processed feed materials, Agri-footprint now also contains markets mixes of important processed feed materials like soybean meal, rapeseed meal and many others (Chapter 5).
4. **Expansion of scope for crops**: more countries are included in the new version, for a complete overview see Appendix C. For several products co-products at cultivation are also added (section 3.2.1.1).
5. **Emission modelling improvements**:
    a. Ammonia emissions from fertilizers are based on tier 2 emission factors (section 3.3.6).
    b. Nitrogen monoxide emission have been added to cultivation inventories (section 3.3.5)
    c. The inclusion of co-production in cultivation (section 3.2.1.1) has influenced crop residue calculations and associated emissions.
6. **Amino acids for feed**: based on Evonik data (section 8.7).

	AFP 1.0	AFP 2.0	AFP 3.0	AFP 4.0	AFP 5.0
Crops	30	>300	>1000[1]	>1350[1]	**>1700[1]**
(Intermediate) products from processing	100	200	500	500	**700**
Market mixes				64	**398**
Food products	35	86	163	163	**188**
Animal production systems	4	4	4	4	**4**

Table 2-1: Number of process included in Agri-footprint by version.

[1] Agri-footprint includes inventories for seed production from version >= 3.0

3 Cultivation of crops



3.1 Introduction and reader's guidance

Data on crop cultivation is collected on a country basis and based on publicly available sources. Data has been updated to the reference year 2016 data during the development of Agri-footprint 5.0, since most publicly data is available for this year. For the crop cultivation model in Agri-Footprint, the following outputs, inputs and resources are considered:

- Crop yield (kg crop product / ha cultivated)
  - Including co-production and allocation properties (price, dry matter, gross energy content)
- Water use for irrigation
- Land occupation
- Land transformations
- Animal manure inputs (type and application rate / ha cultivated)
- Fertilizer inputs (various types for NPK)
- Capital good usage
- Lime input
- Start material input (called "seeds" in previous versions)
- Transport requirements for all of inputs
- Pesticide inputs
- Energy inputs (type and quantity / ha cultivated)

From these resources and inputs, the following emissions are quantified in the crop cultivation model:

- Nitrous oxide emissions
- Ammonia emissions
- Nitrate emissions
- Nitric oxide emissions
- Carbon dioxide emissions (LUC, lime, urea and urea solutions)
- Phosphorus emissions
- Pesticide emissions
- Heavy metal emissions
- Specific emissions:
  - Methane emissions for rice
  - Peat emissions for palm oil cultivation

All crop cultivation processes that have been modelled have a similar structure, an example of the crop cultivation process card in SimaPro® is shown in Figure 3-1.

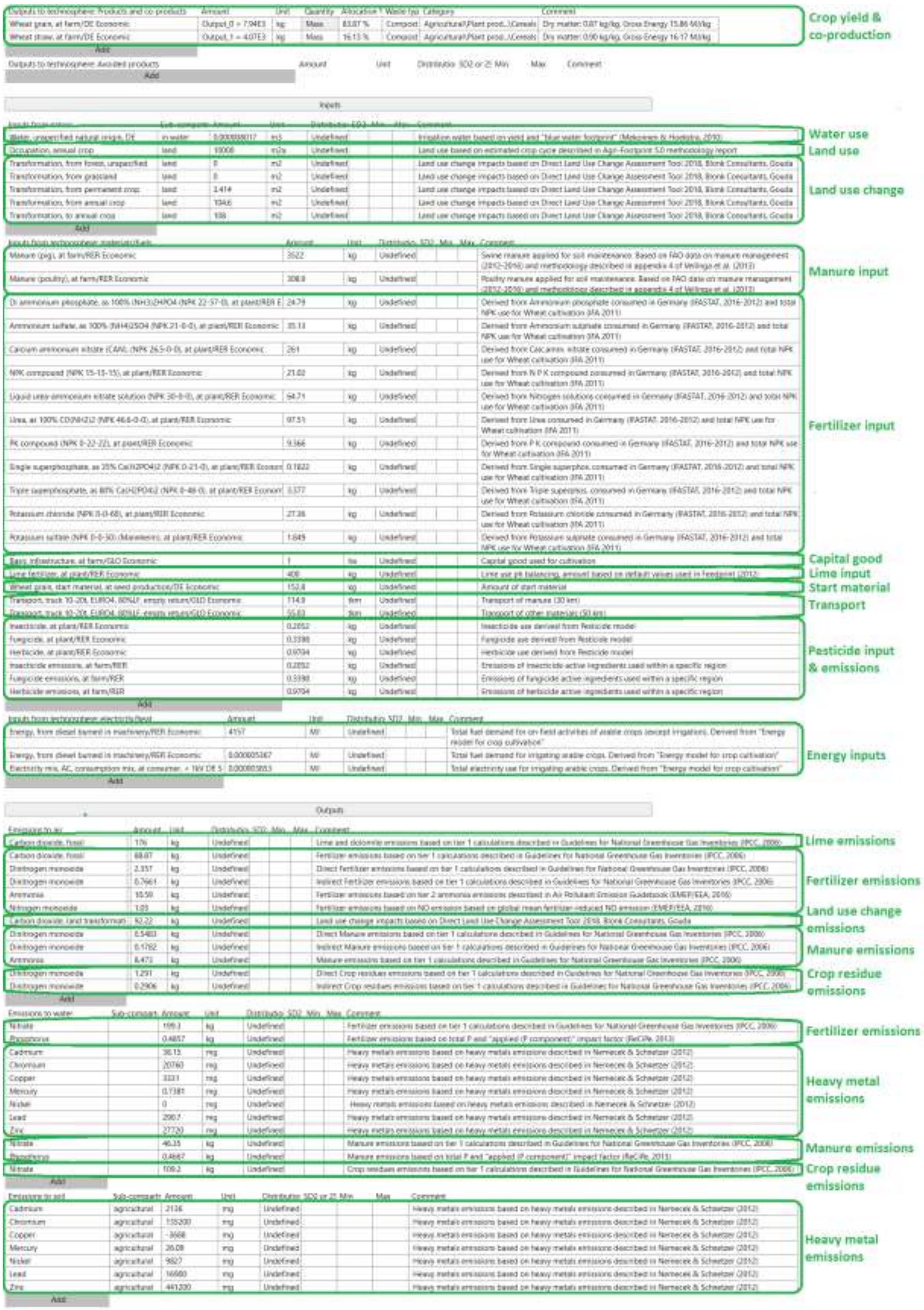


Figure 3-1: Cultivation LCI example of Wheat cultivation in Germany as shown in SimaPro

Data on crop cultivation is a combination of:

- Activity data that is directly derived from publicly available data
- Activity data that is obtained through modelling using publicly available data
- Emission modelling using international standards based on the gathered activity data

3.2 Collected activity data

3.2.1 Yield

Yield of almost all crops in Agri-footprint are based on yields per harvested area provided in FAO Statistics (FAO, 2018a), using a five-year average from 2012 till 2016. One hectare of harvested area therefore becomes the functional unit of the LCI, unless something else is specified. From these five datapoints the standard deviation is obtained. Some crops are not reported in FAO Statistics, these include grass, maize silage and lucerne. The LCI's of these specific crops are largely copied from previous Agri-footprint versions.

3.2.1.1 Co-production

In the new Agri-footprint version, the yield of the co-product is based on the fraction of "Above ground dry matter" (AGDM) or crop residues that can be harvested. The default harvesting factors for crop(groups) are based on "sustainable removal rates" or "practically removable fractions". Since harvesting of the co-product varies considerably around the world, largely depending on demand for these roughages locally, it was chosen to use half of the maximum removal rates from literature. This resulted that following removal fractions are used in Agri-footprint:

- 33.5% for all cereals, except maize (15%), based on a "sustainable removal fraction" of two-thirds for cereals and 30% for maize (Searle & Bitnere, 2017).
- 10% for all pulses, based on the "practically removable fraction" of pulses (Mcdonald, 2010)
- 30% for cottonseed, linseed, rapeseed and soybeans, based on "typically recoverable fractions" (Copeland & Turley, 2008).

3.2.1.2 Properties of the products

Dry matter content and gross energy content of the products are based on (INRA, CIRAD, & AFZ, 2018; USDA, 2018). Economic value of the main and co-products are based on market trading prices for feed commodities in the United Kingdom[2][3].

Table 3-1: Prices used for economic allocation of specific crop groups in Agri-footprint

Product(group)	Price (£/kg)	Co-product	Price (£/kg)	Comment
Cereal grain	0.16	Cereal straw/stover	0.6	Cereals based on wheat prices
Pulse	0.23	Pulse straw	0.03	Pulses based on pea prices
Linseed Rapeseed Soybeans	0.3	Straw	0.05	All three crops based on rapeseed prices
Cottonseed	0.175	Cottonlint	0.95	For US cultivations only

[2] https://www.fwi.co.uk/prices-trends
[3] https://farming.co.uk/prices/baled-hay-straw

3.2.2 Irrigation water

The amount of irrigation water for all Agri-footprint cultivation processes is based on the 'blue water footprint' assessment of (Mekonnen & Hoekstra, 2010a). The estimation of irrigation water is based on the CROPWAT approach (Allen, Pereira, Raes, Smith, & Ab, 1998). The blue water footprint refers to the volume of surface and groundwater consumed as a result of the production of a good. The model used takes into account grid-based dynamic water balances, daily soil water balances, crop water requirements, actual water use and actual yields. The water footprint of crops have been published per country in m^3/tonne of product (Mekonnen & Hoekstra, 2010a). Combined with FAO yields (2012-2016) the blue water footprint is calculated in m^3/ha.

It was chosen not to include 'green water footprint' or rainwater to cultivation inventory. This is because rainwater is not separately included in most impact assessment methods, hereby the water footprint would skyrocket when rainwater would be added to the LCI. Instead, the amount of rainwater is added to the overall process description as reference. In previous versions it was possible to have an LCI with no irrigation water, hereby assuming the cultivation is a rainfed system. In the current version it is only possible to have no irrigation when there is a green water footprint reported. This is the reason why rapeseed cultivation in Greece and sorghum cultivation in Nigeria are moved to "obsolete", since there is no blue and green water footprint reported, meaning the LCI is not complete.

Water use is reported in Agri-footprint as "Water, unspecified natural origin" (sub-compartment 'in water'), with a specific country suffix, making the elementary flow region specific (e.g. "Water, unspecified natural origin, FR" – in water). Hereby the user is enabled to perform water stress related impact studies.

3.2.3 Land occupation

Land occupation in LCA is accounted in m^2a, which can be explained as the area of occupation (m^2) multiplied by the time of occupation (a) required for a certain production process. Up until Agri-footprint v4.0 land occupation was calculated solely based on the yield definitions used in FAOstat, which (in short) is crop production divided by harvested area. Implicitly we assumed that one harvest always represented one crop cycle of 1 full year. This works reasonably well for annual crops that are cultivated in the temperate climate zone and for perennial crops.[4] However, for crops that are cultivated in a multi-cropping cycle within the same year this approach leads to a serious overestimation of the land occupation.[5] For example, rice in China can be harvested two and sometimes even three times a year from the same plot, which would lead to an overestimation of land occupation of 2-3 times. Unfortunately, little (statistical) data is available regarding this subject.

Therefore, a rough method was devised to better estimate the land occupation of multi-cropping systems. Our approach compares the harvested area of potential multi-crops[6] with the area actually in use for these crops. In case the harvested area is higher than the crop area for a certain country a correction factor is calculated and applied in the LCIs. This means that the land occupation in the inventory of some crops is lower than 10,000 m2a. Such an inventory still represents the cultivation of 1 ha of the specific crop, it just indicates that the cultivation period is shorter than 1 year, because it is 'potentially' part of multi-cropping system.

3.2.4 Land use change

Fossil CO_2 emissions resulting from direct land use change were estimated using the "Direct Land Use Change Assessment Tool version 2018" that was developed alongside the PAS 2050-1 (BSI, 2012). This tool provides a predefined way of calculating greenhouse gas (GHG) emissions from land use change based on FAO statistics and IPCC calculation rules, following the PAS 2050-1 methodology. GHG emissions arise when land is transformed from one use to another. The most well-known example of this is conversion of forests to crop land. This tool can be used to calculate the emissions for a specific country-crop combination and attribute them to the cultivated crops.

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[4] For which the yield is reported in FAOstat on a full year basis by definition.

[5] For more information: http://www.agri-footprint.com/2018/04/18/behind-the-scenes-double-cropping/

[6] In this first version we have considered crops from the following three FAO product groups as potential multi-crops: "1 - Cereals and cereal products", "4 - Pulses and derived products" and "7 - Vegetables and derived products"

The calculation has been under development continuously since the publication of the PAS2050-1 and has been reviewed by the World Resource Institute and has, as a result, earned the ‘built on GHG Protocol’ mark. This tool can be used to quantify land use change emissions in conformance with the GHG Protocol standards (http://www.ghgprotocol.org/standards). The tool provides three basic functionalities, based on data availability of the user. All these approaches are described in the PAS 2050-1 published by BSI, and are made operational in this tool using various IPCC data sources (IPCC, 2006d).

For Agri-footprint, the option “calculation of an estimate of the GHG emissions from land use change for a crop grown in a given country if previous land use is not known” was used. This estimate is based on a number of reference scenarios for previous land use, combined with data from relative crop land expansions based on FAOSTAT data (FAO, 2015). These FAO statistics then provide an estimate of the share of the current cropland (for a given crop) which is the result of land use change from forest and/or grassland to cropland. This share is calculated based on an amortization period of 20 years, as described in the PAS 2050-1. This results in three scenarios of land transformation (m^2/ha*year): forest to cropland, grassland to cropland, and transformation between perennial and annual cropland, depending on the crop under study. The resulting GHG emissions are then the weighted average of the carbon stock changes for each of these scenarios. We use the weighted average because, in our opinion, this most accurately estimates the Land Use Change. In the development of Agri-footprint we have the principles that we want to provide consistent data across inventories, and the 'best estimate' rather than a worst-case approach, which the PAS 2050-1 advices. Please see Annex B of the PAS2050-1 for an example calculation (BSI, 2012).

The carbon stock change calculations used for each are based on IPCC rules, and the basic approach is to first calculate the carbon stocks in the soil and vegetation of the old situation and then subtract these from those of the new situation, to arrive at the total carbon stock change. The assumptions for carbon stocks are dependent upon country, climate & soil type. A nice example of such a calculation is provided in the 'Annotated example of a land carbon stock calculation' document, which can be found European Commissions Biofuel site. The soil organic carbon changes and related biomass references are taken from various IPCC tables, which are documented in the direct land use change tool itself.

The calculated CO_2 emissions from land use change (LUC) have been added in the database, the substance flow name is “Carbon dioxide, land transformation”. Note that land use change is also reported in m^2.

3.2.5 Nitrogen from manure

The calculation for manure application rates are based on the methodology used in the Feedprint study (Vellinga et al., 2013a). The manure application rates are estimated using statistics on the total number of animals, the manure produced and the total area on which manure can be applied. This estimation results in an average amount of manure applied per hectare (independent of the crop being cultivated). In reality, the amount of manure applied will depend on the specific crop that is being grown and on the geographic and temporal availability of manure. However, such detailed information is not available and since application of manure will be of benefit to arable soil for a number of years and cropping cycles (as it releases nutrients relatively slowly), this average manure application rate is maintained/justified.

Amount of nitrogen from poultry and swine manure is derived from FAO Statistics on manure management (FAO, 2019a), using 5 year average (2012-2016). Based on the methodology described in the Feedprint study, only manure from swine and poultry are assumed to be applied to arable agricultural soils. A 30% loss of N content is assumed for manure during storage, which is common for swine manure (IPCC, 2006b). Using the nitrogen content of swine and poultry manure (Wageningen UR, 2012b), the total amount of manure from poultry and manure ‘as is’ are quantified which is added to the LCI.

3.2.6 Inorganic fertilizer application rates

The fertilizer information in Agri-footprint is derived using statistics and aggregate data to estimate application rates for crops in specific regions. The majority of these fertilizer application rates, in terms of NPK per crop country combination were derived from the "NPK model". The model is based on national statistics available on NPK land application per country (IFA, 2019a), production and harvested area of country-crop combinations (FAO, 2018a) and estimates of fertilizer use by crop category per country (Heffer, Gruère, & Roberts, 2017). More information about the NPK model can be found in 0. Since the NPK model cannot determine the NPK use for countries member of the European Union and for some specific crops, other sources were used as well. These include: Pallière (2011) for crops in Europe, and data from Rosas (2011) and Fertistat (FAO, 2011) for crops outside of Europe. Data from Pallière were preferred, because it was more recent. The source of NPK for fertilizer use is mentioned in the overall process description for each specific crop.

To match these total N, P and K application rates, to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.), 5 year average (2012-2016) data on regional fertilizer consumption rates from IFA statistics were used (IFA, 2019b).

3.2.7 Capital goods

The capital goods in cultivation processes are called "Basic infrastructure", which is the same process as modelled in the PEFCR for feed (European Commission, 2018a). The assumption is that 30 m^2 of roads and pavements are applied per hectare. Using concrete slabs, 15 cm thick, lifetime of 33.3 years (Wageningen UR, 2015b) and density of 2400 kg/m^3, the total concrete input for basic infrastructure can be determined, which is 327.27 kg concrete per hectare.

3.2.8 Lime

Lime input for adapting the soil acidity for Agri-footprint cultivation processes is assumed to be 400 kg by default, independent of country or crop. This is based on lime application rates described in Feedprint, which uses an uniform distribution between 0 and 800 kg lime for every crop country combination (van Zeist et al., 2012a).

3.2.9 Seed input

Seed input or start material for cultivation is based on FAO crop cultivation statistics (FAO, 2016). Note that seed inputs are not included in the most recent versions of FAO statistics on crop cultivation. Seed input in Agri-footprint is based on 5-year average data from 2009 till 2013. In Agri-footprint versions 3.0 and 4.0, seed input was based on crop county specific data, in which the seed input varied considerably among countries, due to data quality issues. In order to tackle this, it was chosen to use global average seed input for each crop as start material, based on the same data[7].

Yield correction for cultivation of start material

In AFP 3.0 and 4.0 the background process of seed material was a copy of the cultivation process of the same crop country combination, with the exception that the yield of the seed background process is 80% of the cultivation process. Hereby the seed production process is less productive and in terms of environmental performance the seed has higher environmental burdens.

In AFP 5.0, the yield correction factor is different per crop(type) based on data of Feedprint.

[7] http://www.agri-footprint.com/2018/03/15/behind-the-scenes-seed-application-and-seed-production-in-agri-footprint/

Table 3-2: Overview of assumptions in Feedprint cultivation seed production that is applied in Agri-footprint

Group:	Yield Ratio:	Includes:
Cereals	1	Barley, oat, rice, rye, sorghum, triticale, wheat
Potatoes	0.66	Potatoes,
Maize	0.33	Maize
Oilseed	0.57	Linseed, rapeseed, sunflower seed,
Grasses	0.15	Grasses
Forage legumes	0.06	Lucerne
Grain legumes	1	Lupine, soybean, green peas, green beans, dry beans, dry peas, broad bean, chick peas, cow peas, lentil, pigeon peas
Sugar beet	0.04	Fodder beet, sugar beet, onions, curly kale

3.2.10 Transport requirements

Transport requirements are based on:

- A transportation distance of 30 km for manure
- A transportation distance of 50 km for all other inputs

3.2.11 Pesticide input and emissions

There is a complex relation between total amount of pesticides used and ecotoxicity impact caused, due to large differences between the toxicities (i.e. characterization factors) of individual substances. In order to accurately predict impacts from ecotoxicity, specific pesticides applications are needed (in kg active ingredient (a.i.) per pesticide/ha). In practice, however, this level of detail in pesticide application data is often difficult to achieve. There are only few countries who monitor and report reliable data on the application of pesticide active ingredients per crop.
Agri-footprint 4.0 included a pesticide application inventory based on a thorough literature study. This approach proved difficult to continue as the database grew and limited the possibility of updating the data on a yearly basis.

Agri-footprint version 5.0 includes a completely updated pesticide inventory. In version 5.0, pesticide applications per crop and country of cultivation (kg a.i./ha) were modelled for insecticides, herbicides and fungicides using most recent FAO statistics for total pesticide use (FAO, 2019b) and the modelling rationale explained in Appendix B. Use of statistical data allows for continuous update of this inventory and permits to easily include new crop/country cultivation processes to the growing Agri-footprint portfolio. Moreover, following a modelling logic rather than trying to compile the scarcely available specific pesticide application rates per country and crop, gives, in our opinion, the 'best estimate' of pesticide inputs per crop.
The pesticide inventory in Agri-footprint 5.0 is a default inventory which can be used to gain insights in the toxicity impact of biomass taking into account the limitations as reported in this chapter. Primary data (when available) are always preferred over this inventory.

3.2.12 Energy input

Up until Agri-footprint version 4 energy use was calculated based on data obtained from the farm simulation tool MEBOT (Schreuder, Dijk, Asperen, Boer, & Schoot, 2008). Since AFP version 5, the "Energy model for crop cultivation" was used to determine the energy demand (van Paassen, Kuling, Vellinga, da Motta, & de Boer, 2018). The tool was developed in co-operation between representatives from Wageningen University and Blonk Consultants. The model has a bigger scope and uses the most recent specific indicators, such as yield, mechanization factors and irrigation, to determine the energy use at cultivation stage more accurately. Also, the energy demand for irrigation is reported separately (diesel as well as electricity demand for irrigation), hereby it would be possible to make more detailed contribution analysis of irrigation.

3.3 Modelled emissions

Table 3-3 gives an overview of what emissions are considered and which methods are used to quantify the emission flow. Besides this, not all emissions are considered for the most important aspects. For instance, laughing gas emissions are quantified for fertilizer inputs, manure inputs and crop residues, but is "not applicable" for lime inputs. Please note that ammonia emissions from manure is based on the tier 1 IPCC methods, whereas for fertilizer use ammonia emissions are based on the more detailed method described in EMEP/EEA.

Table 3-3: Overview of modelled emissions, literature source and which aspects are included for the calculations

Emission	Level	Method	Fertilizer	Manure	Crop residues	Lime
(In)direct laughing gas emissions	Tier 1	IPCC (IPCC, 2006b)	Yes	Yes	Yes	-
Ammonia emissions	Tier 1		No	Yes	No	-
Nitrate emissions	Tier 1		Yes	Yes	Yes	-
Carbon dioxide emissions	Tier 1		Yes	-	-	Yes
Nitrogen monoxide emissions	Tier 1	EMEP/EEA (European Environment Agency, 2016)	Yes	No	No	-
Ammonia emissions	Tier 2		Yes	No	No	-
Phosphor emissions		ReCiPe (Goedkoop et al., 2013)	Yes	Yes	No	-
Heavy metal emissions		Nemecek & Schnetzer (Nemecek & Schnetzer, 2011)	Yes	Yes	Yes	Yes

Some emissions are specifically for a certain crop or item, these include:

- Methane emissions for rice cultivation
- Peat emissions for palm oil production

3.3.1 Nitrous oxide (N_2O) emissions

There are a number of pathways that result in nitrous oxide emissions, which can be divided into direct emissions (release of N_2O directly from N inputs) and indirect emissions (N_2O emissions through a more intricate mechanism). Beside nitrous emissions due to N additions, there are other activities that can result in direct nitrous oxide emissions, such as the drainage of organic soils, changes in mineral soil management, and emissions from urine and dung inputs to grazed soils. These latter two categories are not taken into account in the crop cultivation models, as it is assumed that crops are cultivated on cropland remaining cropland and the organic matter contents of the soils does not substantially change, and that cropland is not grazed. The emissions from grazing of pastureland are however included in the animal system models. The following equations and definitions are derived from IPCC methodologies on N_2O emissions from managed soils;

$$N_2O - N_{direct} = N_2O - N_{Ninputs} + N_2O - N_{OS} + N_2O - N_{PRP}$$

Equation 3-1 (IPCC, 2006c)

Where,

$N_2O - N_{Direct}$ = annual direct N_2O–N emissions produced from managed soils, [kg N_2O–N]
$N_2O–N_{N\ inputs}$ = annual direct N_2O–N emissions from N inputs to managed soils, [kg N_2O–N]
$N_2O–N_{OS}$ = annual direct N_2O–N emissions from managed organic soils, [kg N_2O–N]
$N_2O–N_{PRP}$ = annual direct N_2O–N emissions from urine and dung inputs to grazed soils, [kg N_2O–N]

Note that the unit kg N_2O-N should be interpreted as kg nitrous oxide measured as kg nitrogen. In essence, Equation 3-1 to Equation 3-8 describe nitrogen balances. To obtain [kg N_2O], [kg N_2O-N] needs to be multiplied by $\left(\frac{44}{28}\right)$, to account for the mass of nitrogen (2*N, atomic mass 14) within the mass of a nitrous oxide molecule (2*N+1*O, atomic mass 16). See Table 3-4 for a list of emissions factors and constants.

The N_2O emissions from inputs are driven by four different parameters; the application rate of synthetic fertilizer, application of organic fertilizer (e.g. manure), amount of crop residue left after harvest, and annual release of N in soil organic matter due to land use change. The latter was incorporated in the aggregated emissions from land use change as described in 3.2.4.

Beside the direct emissions, there are also indirect emission pathways, in which nitrogen in fertilizer is first converted to an intermediate compound before it is converted to N_2O (e.g. volatilization of NH_3 and NO_x which is later partly converted to N_2O). The different mechanisms are shown schematically in Figure 3-2.

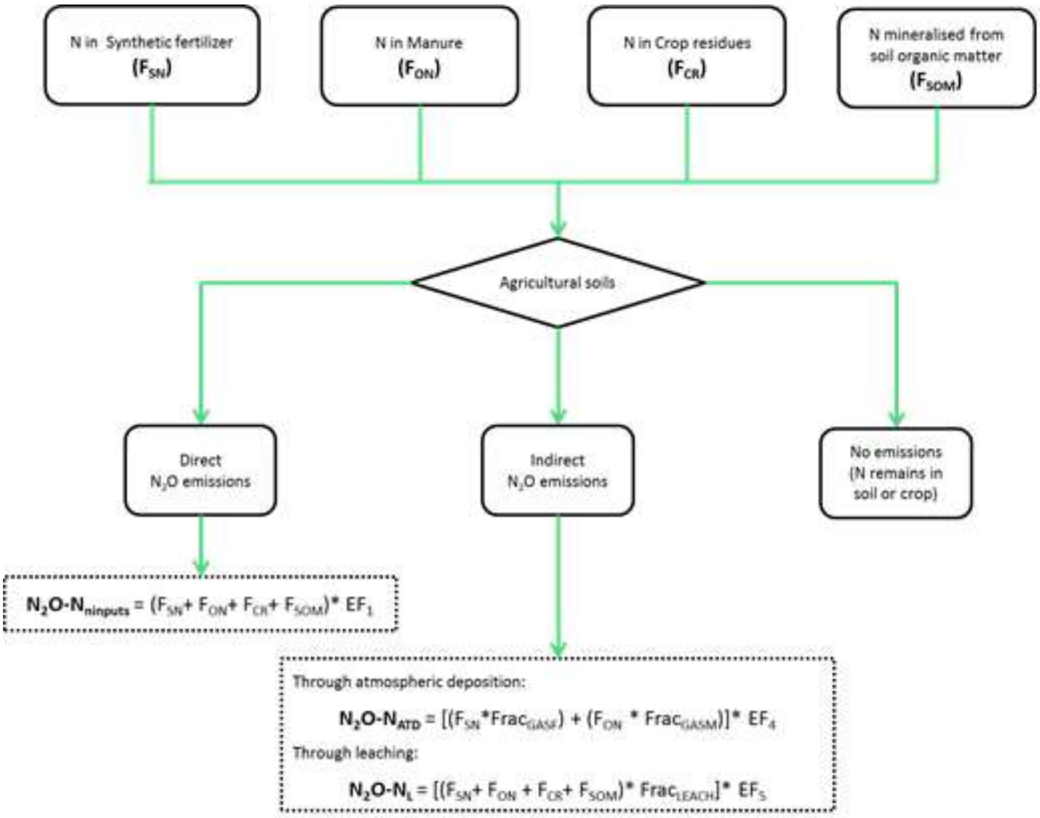


Figure 3-2: Nitrous oxide emission (direct and indirect) from due to different N inputs (IPCC, 2006c).

The equations listed in Figure 3-2, will be discussed in more detail below. First, the major contribution from direct emissions of N_2O is from N inputs:

$$N_2O - N_{Ninputs} = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) * EF_1$$

Equation 3-2 (IPCC, 2006c)

Where,

F_{SN} = the amount of synthetic fertilizer N applied to soils, [kg N]
F_{ON} = the amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, [kg N]
F_{CR} = the amount of N in crop residues (above-ground and below-ground), including N-fixing crops (leguminous), and from forage/pasture renewal, returned to soils, [kg N]

F_{SOM} = the amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management, [kg N]
EF_1 = emission factor for N_2O emissions from N inputs, $[\frac{kg\ N_2O\text{–}N}{kg\ N\ input}]$

As mentioned before, the contribution of F_{SOM} is incorporated in the emissions from land use change, which are calculated elsewhere (see 3.2.4). F_{CR} is dependent on the type of crop and yield and is determined separately. The IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006c) provides guidance on how to do this using an empirical formula and data for a limited number of crops and crop types. The emission factor EF_1 in Equation 3-2 has a default value of 0.01 (i.e. 1% of mass of N from fertilizer and crop residue will be converted to N_2O); as listed in Table 3-4.

In Agri-footprint the direct N_2O emissions are modelled according to the IPCC Tier 1 approach. The uncertainty range of the EF_1 emission factor is very high (0.003 – 0.03) because climatic conditions, soil conditions and agricultural soil management activities (e.g. irrigation, drainage, tillage practices) affect direct emissions.

F_{SN} has been determined using mainly data from Pallière (2011), as described in sections 3.1 and 3.2.6 of this report. The contribution of F_{ON} has been determined on a country basis, as described in the methodology report of the Feedprint study (Vellinga et al., 2013a), which formed the basis of the crop cultivation models in this study, see section 3.1.

In addition, emissions of nitrous oxide from managed organic soils is also taken into account for the cultivation of Oil Palms on tropical peat lands:

$$N_2O - N_{OS} = \left(F_{OS,CG,Trop}\right) * EF_{2,CG,Trop}$$

Equation 3-3 (IPCC, 2006c)

Where,

N_2O–N_{OS}= annual direct N_2O–N emissions from managed organic soils, kg N_2O–N yr^{-1}

$EF_{2,CG,Trop}$= emission factor for N2O emissions from drained/managed organic soils, kg N_2O–N /(ha *yr); Note: the subscripts CG, Trop refer to Cropland and Grassland and Tropical respectively)

There are two other, indirect, mechanisms that also contribute to the total N_2O emissions:

$$N_2O - N_{indirect} = N_2O_{(ATD)} - N + N_2O_{(L)} - N$$

Equation 3-4 (IPCC, 2006c)

Where,

$N_2O_{(ATD)}$–N = amount of N_2O–N produced from atmospheric deposition of N volatilized from managed soils, [kg N_2O–N]
$N_2O_{(L)}$–N = annual amount of N_2O–N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, [kg N_2O–N]

The amount of N_2O that is emitted through atmospheric deposition depends on the fraction of applied N that volatizes as NH_3 and NO_x, and the amount of volatized N that is converted to N_2O:

$$\mathrm{N_2O - N_{ATD}} = \left[\left(\mathrm{F_{SN} * Frac_{GASF}}\right) + \left(\mathrm{F_{on} + F_{prp}}\right) * \mathrm{Frac_{GASM}}\right] * \mathrm{EF_4}$$

Equation 3-5 (IPCC, 2006c)

Where,

F_{SN} = annual amount of synthetic fertilizer N applied to soils, [kg N]
F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, [kg N]
$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, $\left[\frac{kg\ N\ volatilized}{kg\ N\ applied}\right]$
$Frac_{GASM}$ = fraction of applied organic N fertilizer materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilizes as NH_3 and NO_x, $\left[\frac{kg\ N\ volatilized}{kg\ N\ applied\ or\ deposited}\right]$
EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, $\left[\frac{kg\ N_2O-N}{kg\ NH_3-N + NO_x-N\ volatilized}\right]$
F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, [kg N]

In Agri-footprint no mixed enterprise farming systems are considered. Therefore, in the crop cultivation models, F_{PRP} was set to 0 (no urine and dung from grazing animals). However, emissions from grazing were taken into account in the animal systems, where appropriate. The default emission factor EF_4 and the default fractions are listed in Table 3-4. Equation 3-6 shows the calculation procedure for determining N_2O emission from leaching of applied N from fertilizer (SN and ON), crop residue (CR), grazing animals (PRP) and soil organic matter (SOM).

$$N_2O - N_L = \left[(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * Frac_{LEACH-(H)}\right] * EF_5$$

Equation 3-6 (IPCC, 2006c)

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, $\left[\frac{kg\ N}{kg\ of\ N\ additions}\right]$
EF_5= emission factor for N_2O emissions from N leaching and runoff, $\left[\frac{kg\ N_2O-N}{kg\ N\ leached\ and\ runoff}\right]$

3.3.2 Ammonia (NH_3) and nitrate (NO_3^-) emissions – tier 1

Again, the IPCC calculation rules (IPCC, 2006c) were applied to determine the ammonia and nitrate emissions. This approach of modelling ammonia volatilization was used only for emissions from manure; the ammonia volatilization from inorganic fertilizer was indeed modelled following EMEP/EEA guidelines (see chapter 3.3.6). It was assumed that all nitrogen that volatizes converts to ammonia, and that all nitrogen that leaches is emitted as nitrate. In essence, Equation 3-7 & Equation 3-8 are the same as the aforementioned equations for nitrous emissions from atmospheric deposition and leaching (Equation 3-5 & Equation 3-6) but without the secondary conversion to nitrous oxide.

Ammonia (NH_3) emissions:

$$NH_3 - N = (F_{SN} * Frac_{GASF}) + (F_{ON} + F_{PRP}) * Frac_{GASM}$$

Equation 3-7 (IPCC, 2006c)

Where,

NH_3-N = ammonia produced from atmospheric deposition of N volatilized from managed soils, [kg NH_3–N]

Nitrate (NO_3^-) emissions to soil:

$$NO_3^- - N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * Frac_{LEACH-(H)}$$

Equation 3-8 (IPCC, 2006c)

Where,

NO_3^--N = nitrate produced from leaching of N from managed soils, [kg NO_3^--N]

3.3.3 Carbon dioxide (CO_2) emissions

Carbon dioxide emissions from lime, dolomite and urea containing compounds are included in the inventory. Both lime and dolomite are resources of fossil origin. Carbon dioxide emissions from urea containing compounds are included as well since: "CO_2 removal from the atmosphere during urea manufacturing is estimated in the Industrial Processes and Product Use Sector (IPPU Sector)" (IPCC, 2006c). In Agri-footprint, two urea containing compounds are present: urea (which is 100% urea) and liquid urea ammonium nitrate solution (which contains 36.6% urea).

CO_2 emissions from limestone, dolomite and urea containing compounds:

$$\mathrm{CO_2 - C_{em}} = (\mathrm{M_{Limestone}} * \mathrm{EF_{Limestone}}) + (\mathrm{M_{Dolomite}} * \mathrm{EF_{Dolomite}}) + (\mathrm{M_{Urea}} * \mathrm{EF_{Urea}})$$

Equation 3-9 (IPCC, 2006c)

Where,

$CO_2–C_{em}$ = C emissions from lime, dolomite and urea application, [kg C]
$M_{limestone}$, $M_{dolomite}$, M_{urea} = amount of calcic limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) or urea respectively, in [kg]
$EF_{limestone}$, $EF_{dolomite}$, EF_{urea} = emission factor, $\left[\frac{\boldsymbol{kg\ C}}{\boldsymbol{kg\ of\ limestone, dolomite\ or\ urea}}\right]$

Default emission factors are reported in Table 3-4.

3.3.4 IPCC tier 1 emissions factors and constants

Table 3-4: IPCC Tier 1 emission factors and constants.

IPCC Tier 1 Emission factors and constants [and units]	Value [-]
$EF_1 \left[\frac{kg\ N_2O-N}{kg\ N_{applied}}\right]$	0.01
$EF_{2,CG,Trop} \left[\frac{kg\ N_2O-N}{ha*yr}\right]$	16
$EF_4 \left[\frac{kg\ N_2O-N}{kg\ N_{volatized}}\right]$	0.01
$EF_5 \left[\frac{kg\ N_2O-N}{kg\ N_{leached}}\right]$	0.0075
$EF_{Dolomite} \left[\frac{kg\ CO_2-C}{kg\ Dolomite}\right]$	0.13
$EF_{Lime} \left[\frac{kg\ CO_2-C}{kg\ lime}\right]$	0.12
$EF_{Urea} \left[\frac{kg\ CO_2-C}{kg\ Urea}\right]$	0.2
$Frac_{GASM} \left[\frac{kg\ NH_3-N}{kg\ N_{in\ manure\ applied}}\right]$	0.2
$Frac_{GASF} \left[\frac{kg\ NH_3-N}{kg\ N_{in\ fertilizer\ applied}}\right]$	0.1
$Frac_{LEACH} \left[\frac{kg\ NO_3^- - N}{kg\ N_{applied}}\right]$	0.3
Conversion from kg CO2-C to kg CO2	$\left(\frac{44}{12}\right)$
Conversion from kg N2O-N to kg N2O	$\left(\frac{44}{28}\right)$
Conversion from kg NH3-N to kg NH3	$\left(\frac{17}{14}\right)$
Conversion from kg NO3--N to kg NO3-	$\left(\frac{62}{14}\right)$

3.3.5 Nitric oxide (NO) emissions

For Agri-Footprint version 5.0, nitric oxide emissions from fertilizer use are considered. Although nitric oxide is produced as an intermediate product of the nitrification and denitrification processes, no methodology has been developed in the IPCC guidelines of 2006 to quantify its emission. Therefore, a global mean fertilizer induced NO emission of 0.7% was used to determine these emissions, derived from EMEP/EEA guidelines (European Environment Agency, 2016)

3.3.6 Ammonia (NH_3) emissions – tier 2

For ammonia emissions from inorganic fertilizers a more detailed tier 2 approach is used based on emission factors for specific type of fertilizers described by EMEP/EEA (European Environment Agency, 2016). All eight inventoried nitrogen containing fertilizers in chapter 3.2.6 each have their own specific emission factor described in Figure 3-3.

	Climate					
	Cool		Temperate		Warm	
	normal pH (a)	high pH (b)	normal pH (a)	high pH (b)	normal pH (a)	high pH (b)
Anhydrous ammonia (AH)	19	35	20	36	25	46
AN	15	32	16	33	20	41
Ammonium phosphate (AP) (c)	50	91	51	94	64	117
AS	90	165	92	170	115	212
CAN	8	17	8	17	10	21
NK mixtures (d)	15	32	22	33	20	41
NPK mixtures (d)	50	91	67	94	64	117
NP mixtures (d)	50	91	67	94	64	117
N solutions (e)	98	95	100	97	126	122
Other straight N compounds (f)	10	19	14	20	13	25
Urea(g)	155	164	159	168	198	210

(a) A 'normal' pH is a pH of 7.0 or below.
(b) A 'high' pH is a pH of more than 7.0 (usually calcareous soils).
(c) AP is the sum of ammonium monophosphate (MAP) and diammonium phosphate (DAP).
(d) NK mixtures are equivalent to AN, NPK and NP mixtures, which are 50 % MAP plus 50 % DAP.
(e) N solutions are equivalent to urea AN.
(f) Other straight N compounds and equivalent to calcium nitrate.
(g) Urea is an organic compound with the chemical formula $CO(NH_2)_2$.

Figure 3-3: Emission factors for ammonia emissions from fertilizers (g NH_3/kg N applied) (European Environment Agency, 2016)

Due to the lack of data on the pH of soils, it is assumed that all soils around the world are “normal”. Using the climate zone criteria described in the reference and average temperatures of countries around the world, each country is either classified as “cool”, “temperate” or “warm”.

3.3.7 Phosphor emissions

The phosphorous content of synthetic fertilizers and manure is emitted to the soil. Up to version 2 of the Agri-footprint database these were modelled as an emission of substances:

- Synthetic fertilizer, applied (P component)
- Manure, applied (P component)

The emissions of these substances have an impact on freshwater eutrophication. These substance flows were covered both by ReCiPe and ILCD, but to make the dataset more widely applicable and to avoid any confusion about the magnitude of phosphorus emitted, these flows have been re-calculated into emissions of phosphorus (to water), using an emission factor of 0.05 and 0.053 for manure and synthetic fertilizer respectively. (e.g. when 1 kg of P in manure is applied on a crop, this results in 0.05 kg emitted to soil). These emission factors for the above mentioned substances are derived from a study by Struijs, Beusen, Zwart, & Huijbregts (2010). The fraction of phosphorus emission that actually reaches freshwater is approximately 0.05 for phosphorus from synthetic fertilizer and manure.

3.3.8 Heavy metal emissions

The emissions of heavy metals was based on a methodology described in Nemecek & Schnetzer (2012). The emissions are the result of inputs of heavy metals due to fertilizer and manure application and of deposition and outputs of heavy metals due to leaching and removal of biomass.

Heavy metals are added to the soil due to application of fertilizers and manure and due to deposition. The heavy metal content of fertilizers and manure was based on literature as stated in Table 3-5 and Table 3-6, respectively. The deposition of heavy metals is stated in

Table 3-7.

Table 3-5: Heavy metal content of fertilizers (Mels, Bisschops, & Swart, 2008)

Mineral fertilizers	Unit	Cd	Cu	Zn	Pb	Ni	Cr	Hg
N-fertilizer	mg/kg N	6	26	203	54.9	20.9	77.9	0.1
P- fertilizer	mg/kg P_2O_5	39.5	90.5	839	67	88.3	543	0.3
P- fertilizer	mg/kg P	90.5	207	1,923	154	202	1,245	0.7
K- fertilizer	mg/kg K_2O	0.1	4.8	6.2	0.8	2.5	5.8	0
K- fertilizer	mg/kg K	0.2	8.7	11.3	1.5	4.5	10.5	0.1
Lime	mg/kg CaO	0.5	14.6	66.9	9.7	10.5	14.7	0.1
Lime	mg/kg Ca	0.7	20.4	93.6	13.6	14.7	20.6	0.1
NPK-S 21-4-7	mg/kg N	0.2	6.9	76	2	22	37	0
NPK-S 21-4-7	mg/kg P	0.1	2.3	25	0.7	7	12	0

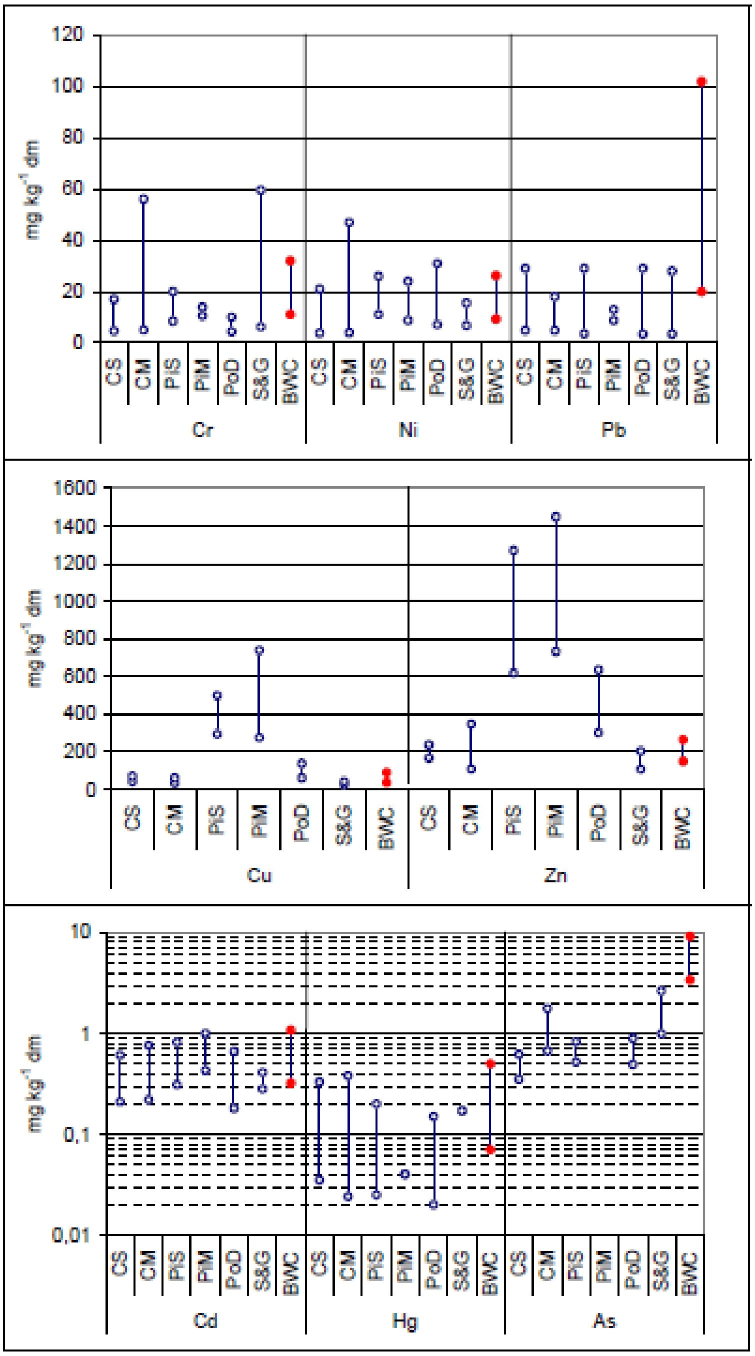
Table 3-6: Heavy metal content of manure (Amlinger, Pollak, & Favoino, 2004)

Manure	Unit	Cd mg/kg Fertilizer	Cr mg/kg Fertilizer	Cu mg/kg Fertilizer	Hg mg/kg Fertilizer	Ni mg/kg Fertilizer	Pb mg/kg Fertilizer	Zn mg/kg Fertilizer
Pigs	mg/kgDM	0.45	20.65	51.5	0.1975	18.75	14.25	214.75
Cattle	mg/kgDM	0.64	13.225	452.25	0.0775	17.425	13.55	1018
Poultry	mg/kgDM	1.52	8.7	99	0.085	19.05	16.2	469

Above European values are also used for other continents because data is not available, incomplete or it is not stated if the values are 'per kg dry matter' or 'per kg manure as is'. Please note that ranges in heavy metal contents of animal manure are large as shown in Table 3-6. Please note that the amount of copper (Cu) and zinc (Zn) in pig slurry and manure are high because additional copper and zinc is added to the feed by pig farmers for animal health reasons.

It is assumed that only pig and poultry manure are applied in cultivation of arable crops[8] because cattle systems are often closed-loop systems. The ratio pig / poultry manure is based on FAO data on the amount of available nitrogen per type of animal manure.

[8] Please note that cattle manure is applied on those crops which are cultivated on dairy farms for feed (e.g. maize silage) due to the closed system.



CS…cattle slurry; CM…cattle manure; PiS…pig slurry; PiM…pig manure;
PoD…poultry dung; S&G…sheep and goose manure; BWC…biowaste compost

Figure 3-4: Range of heavy metal contents in different animal manures in the EU. CS = Cattle slurry, CM =Cattle manure , PiS =Pig slurry , PiM =Pig manure , PoD = Poulty dung, S&G =Sheep and goat manure , BWC = Biowaste compost (Amlinger et al., 2004)

Table 3-7: Deposition of heavy metals (Nemecek & Schnetzer, 2012)

		Cd	Cu	Zn	Pb	Ni	Cr	Hg
Deposition	mg/ha/yr	700	2,400	90,400	18,700	5,475	3,650	50

Heavy metals are removed from the soil via removal of biomass and via leaching. The heavy metal content of biomass of crops is shown in Table 3-8. Leaching of heavy metals to ground water is mentioned in Table 3-9.

Table 3-8: Heavy metals in biomass (Delahaye, Fong, Eerdt, Hoek, & Olsthoorn, 2003)

Crop	Cd (mg/kg DM)	Cr (mg/kg DM)	Cu (mg/kg DM)	Hg (mg/kg DM)	Ni (mg/kg DM)	Pb (mg/kg DM)	Zn (mg/kg DM)
Fodder beets, rapes, carrots	0.04	0.22	1.08	0.0011	0.094	0.154	6.2
Chicory roots	0.04	0.22	1.66	0.0011	0.094	0.154	2.6
Wheat	0.013	2.28	4.1	0.00862	0.86	0.1	24.8
Rye	0.013	0.93	3.11	0.00862	0.86	0.3	28.8
Barley	0.013	2.28	3.9	0.00862	0.19	1	24
Oat	0.013	2.28	3.6	0.00862	0.86	0.05	24.7
Maize	0.52	0.24	1.58	0.01	0.86	1.3	21.6
Triticale	0.013	2.28	4.7	0.00862	0.86	0.14	34
Other cereals	0.013	2.28	4.1	0.00862	0.86	0.1	24.8
Pulses/Lupine	0.02	1.4	8.03	0.013	0.86	0.4	33.7
Oilseeds	0.1	0.5	12.62	0.00862	0.86	1	49.6
Cassava	0.009	2.28	2.92	0.01	0.86	0.9	13
Sweet potato	0.009	2.28	5.7	0.0088	0.86	0.31	5.6
Rapeseed	0.02	1.4	4.4	0.013	1	0.4	46.5
Potatoes	0.03	0.4	1.1	0.003	0.25	0.03	2.9
Sugar beet	0.04	0.22	1.1	0.0011	0.094	0.154	6.2
Chicory	0.03	0.4	2.1	0.003	0.25	0.03	12.5
Onions	0.012	0.4	0.4	0.002	0.04	0.021	1.6
Maize silage	0.1	0.24	3.6	0.01	0.861	0.1	36
Onions	0.04	0.22	1.1	0.0011	0.094	0.154	6.2
Maize silage	0.133	0.72	7.4	0.01	0.9	1.91	22.7
Fodder beet	0.2	1.32	8.3	0.0188	3.9	2.25	43
Grass fresh	0.2	0.6	8.3	0.0188	3.9	2.25	44
Vegetables & fruit	0.03	0.5	0.5	0.002	0.14	0.54	4

*Not referred to in (Delahaye et al., 2003) but average of other crops.

Table 3-9 : Heavy metal leaching to groundwater (Nemecek & Schnetzer, 2012)

		Cd	Cu	Zn	Pb	Ni	Cr	Hg
Leaching	mg/ha/yr	50	3,600	33,000	600	n.a.	21,200	1,3

An allocation factor is required because not all heavy metal accumulation is caused by agricultural production. Heavy metals are also caused by deposition from other activities in the surrounding area. The allocation factor is calculated as follows:

$$A_i = M_{agro\ i} / (M_{agro\ i} + M_{deposition\ i})$$

Equation 3-10

$\boldsymbol{A_i}$ = allocation factor for the share of agricultural inputs in the total inputs for heavy metal i
$\boldsymbol{M_{agro\ i}}$ = input due to agricultural activities (fertilizer and manure application) for heavy metal i
$\boldsymbol{M_{deposition\ i}}$ = input due to deposition for heavy metal i

Heavy metal emissions into the ground and surface water are calculated with constant leaching rates as:

$$M_{leach\ i} = m_{leach\ i} * A_i$$

Equation 3-11

Where,

$\boldsymbol{M_{leach\ i}}$ = leaching of heavy metal i to the ground and surface water
$\boldsymbol{m_{leach\ i}}$ = average amount of heavy metal emission (Table 3-9)
$\boldsymbol{A_i}$ = allocation factor for the share of agricultural inputs in the total inputs for heavy metal i

Heavy metals emissions to the soil are calculated as follows:

$$M_{soil\ i} = (\Sigma inputs_i - \Sigma outputs_i) * A_i$$

Equation 3-12

Where,

$\boldsymbol{M_{soil\ i}}$ = accumulation in the soil of heavy metal i
$\mathbf{A_i}$ = allocation factor for the share of agricultural inputs in the total inputs for heavy metal i

$$\Sigma inputs_i = A * A_{content\ i} + B * B_{content\ i} + C$$

Equation 3-13

Where,

$\boldsymbol{A}$ = fertilizer application (kg/ha/yr)
$\boldsymbol{A_{content\ i}}$ = heavy metal content i for fertilizer applied (Table 3-5)
$\boldsymbol{B}$ = manure application (kg DM/ha/yr)
$\boldsymbol{B_{content\ i}}$ = heavy metal content i for manure applied (Table 3-6)
$\boldsymbol{C}$ = deposition (Table 3-7)

$$\Sigma outputs_i = M_{leach\ i} + D * D_{content\ i}$$

Equation 3-14

Where,

$\boldsymbol{D}$ = yield (kg DM/ha/yr)
$\boldsymbol{D_{content\ i}}$ = heavy metal content i for crop (Table 3-8)

When more heavy metals are removed from the soil via leaching and biomass than is added to the soil via fertilizers, manure and deposition, the balance can result in a negative emission.

3.3.9 Specific emissions

3.3.9.1 Methane emissions in rice cultivation

Methane emissions that are a result of rice cultivation have been inventoried for rice cultivations in Agri-footprint. In version 5.0 the emission factors for rice cultivation is based on information from a single public source. FAOstat reports on the “implied emissions factor for CH4” for rice cultivation for 120+ countries (FAOSTAT, 2019). This factor is converted from gram methane/harvested square meter to kg biogenic methane per harvested hectare in the LCI’s for rice cultivation.

3.3.9.2 Peat oxidation for oil palm fruit cultivation

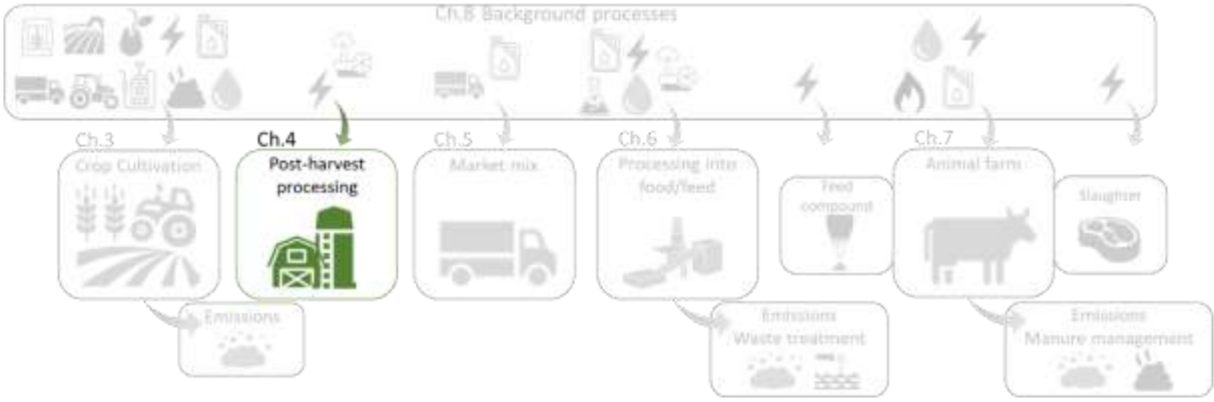
For peat oxidation is currently only considered for oil palm fruit cultivation in Malaysia and Indonesia. Using the IPCC guidelines for tropical soils, 16 kg $N\text{-}N_2O$ and 20 ton $C\text{-}CO_2$ are emitted from peat soils every year (IPCC, 2006e). Fraction peatland for Malaysian oil palm fruit cultivation is 11.8% and for Indonesia this number is 30% (Wetlands International, 2011).

3.4 Integration of USDA LCA commons crop data in Agri-footprint

In version 4.0 of Agri-footprint, 117 crop products and co-products have been inventoried and added to the database. The inventoried data was collected by the USDA. The United States Department of Agriculture (USDA) hosts a Life Cycle Assessment (LCA) data repository called the LCA commons (https://www.lcacommons.gov/). The aim of this repository is to support LCA researchers by providing LCA datasets related to Agriculture. In 2012, Cooper et al. published the first version of the crop production dataset (Cooper, Kahn, & Noon, 2012). These datasets where subsequently updated and expanded (Cooper, 2013), (Cooper, Noon, Kahn, & Johnson, 2014), (Cooper, 2015).

These USDA crops have been copied from Agri-footprint 4.0 and added without any alteration to Agri-footprint 5.0. More documentation on the USDA crops can be found in Agri-footprint 4.0 – Part 2 documentation.

4 Processing of crops at post-harvest



The post-harvest processing is a new step added to the modelled AFP supply chain. It is meant for those crop products that are usually processed directly at farm/orchard, before being commercialized. This is of relevance since FAO data on yield are sometimes expressed as harvested products (e.g. groundnuts, with shell) while FAO data on trade statistics are based on post-harvest processed crops (e.g. groundnuts, shelled). The change of weight should be then included in the transportation; therefore, this intermediate step becomes important.

Two types of post-harvesting processes have been considered for now: deshelling/dehusking of nuts and drying before storage.

4.1 Deshelling/dehusking

This post-harvest process is relevant for groundnuts and coconuts. The share of shell/husk over the total weight (30% for groundnuts and 39% for coconuts) was based on FAOstat for groundnuts. The mass balance for coconuts is based on confidential information from a coconut processor in Sri Lanka. The energy use was based on an average default calculated from different nuts deshelling (cashew, almond and groundnut) literature sources (Table 4-1).

Table 4-1 Electricity and diesel use of nuts used for deriving a nut deshelling default.

		Electricity	Diesel	Source
Cashew	MJ/ton input	11	360	(Jekayinfa & Bamgboye, 2006)
Almond	MJ/ton input	248	18	(Kendall, Marvinney, Brodt, & Zhu, 2015)
Groundnut	MJ/ton input	246	97	(Center for Agricultural and Rural Sustainability, 2012)
Average	MJ/ton input	168	158	

4.2 Drying

Drying of grains and other agricultural products is a common practice that prevents spoilage during storage. It is considered for grains (barley grain, oat grain, rye grain, triticale grain and wheat grain), rapeseed, lucerne and cassava roots. The mass balance is based on the moisture of the harvested product and the typical moisture of the dried product. Moisture content before drying was set at 0.21 kg/kg for grans and rapeseed, 0.8 kg/kg for lucerne and 0.6 kg/kg for cassava root; a safe moisture content after drying, in order to prevent spoilage, was set at 0.12 kg/kg. For grains and rapeseed, it was considered that FAOstat reports the yield as traded, therefore already dried; no moisture loss was then accounted. For products with a high-water content (cassava and lucerne) it was assumed that sun drying was performed until a 0.34 kg/kg moisture content. The rest of the drying was assumed to be performed by a fluid bed dryer (150 MJ electricity/ton of water evaporated and 4500 MJ steam/ton of water evaporated) based on Fox, Akkerman, Straatsma, & Jong de (2010).

5 Market mixes of commodities

In Agri-footprint version 5.0, the market mixes of raw materials have been updated. A new feature is that there are now market mixes of processed materials as well. The market mixes of commodities also contain the transportation requirements for transporting the materials from the various sources to the specific country market.

5.1 Market mix of raw materials

The market mix of specific raw materials is determined by adding the total import of the raw materials from various countries (FAO, 2019c) to a specific country with the national production of the same product (FAO, 2018a). To overcome huge trade and production fluctuations from year to year, 5-year averages are used (2012-2016). For the underlying trading countries, a market mix is constructed in order to determine the source country of the raw material. This can be best explained using an example, as shown in Figure 5-1.

For example, country A is 10% self-sufficient and imports 20% from country B, 30% from country C and 40% from country D. Building a market mix based on the “first layer approach” is quite problematic, since it is quite possible that a specific county only acts as transit country or imports a lot from other countries. Therefore, for each country that trades with country A directly (country B, C and D), their market mixes are inventoried as well. By default, Agri-footprint inventories at least 4 levels deep in order to determine the cultivation countries of the commodity in country A. Since country D does not produce the commodity itself, but only acts as a transit country, it is not part of the overall market mix of the commodity in country A, whereas country F is indirectly the largest cultivator of the commodity in country A

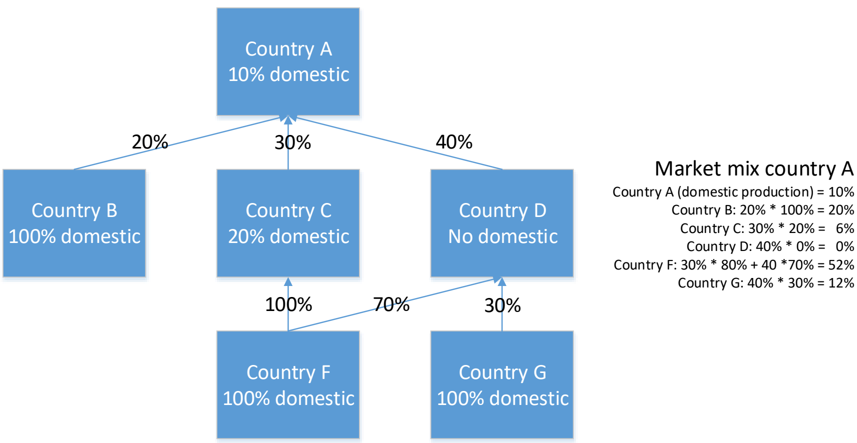


Figure 5-1: Graphic illustration of how market mixes are calculated in Agri-Footprint

Within the algorithm there is a cut-off applied: meaning that if the share of a country is less than 0.5% these are not accounted for in the final mix. Another issue is that not for all countries there is cultivation data available in Agri-footprint. How the final market mix is eventually determined can be best illustrated using an example as shown Table 5-1.

Table 5-1: How the market mix and coverage is estimated, example of Dutch maize (fictive) market mix

Source country	Crop	Quantity (%)	Reporter country	Cultivation data?		Market mix
France	Maize	39.95	Netherlands	TRUE	39.95	45%
Hungary	Maize	11.70	Netherlands	TRUE	11.70	13%
Ukraine	Maize	10.30	Netherlands	TRUE	10.30	12%
Germany	Maize	8.65	Netherlands	TRUE	8.65	10%
Brazil	Maize	8.10	Netherlands	TRUE	8.10	9%
Netherlands (domestic)	Maize	6.16	Netherlands	FALSE		
Romania	Maize	2.85	Netherlands	TRUE	2.85	3%
Argentina	Maize	2.35	Netherlands	TRUE	2.35	3%
Belgium	Maize	2.27	Netherlands	TRUE	2.27	3%
Serbia	Maize	2.21	Netherlands	FALSE		
Russia	Maize	0.86	Netherlands	FALSE		
Slovakia	Maize	0.86	Netherlands	TRUE	0.86	1%
Poland	Maize	0.78	Netherlands	TRUE	0.78	1%
Bulgaria	Maize	0.76	Netherlands	TRUE	0.76	1%
United States	Maize	0.60	Netherlands	TRUE	0.60	1%
	Included	**98.40**		**Coverage:**	**89.18**	**100%**

Based on the trade and production statistics that are available for maize can be seen that 98.4% of all available maize on the Dutch market is from 15 different countries. 1.6% of the market mix comes from countries providing less than 0.5% of the market mix and are therefore cut out. Also, not for all countries there is maize cultivation data available in Agri-Footprint. In the fictive example above, this means that maize cultivation in the Netherlands, Serbia and Russia are excluded from the Dutch market mix. For the datasets for which cultivation data is available, the coverage determines the quality of the market mix. In the case of maize on the Dutch market, 89.2% of maize cultivation data is available. The final market mix is rescaled based on the relative shares of the different countries totaling 100%. For each market mix, the coverage information is given in the comment field of the market mix LCI.

5.2 Market mix of processed materials

The same principle that is used for raw materials is also used for processed materials. Combining trade data with national production of processed crops (FAO, 2018b). Production data for processed crops is quite limited. But with some additional information production data of co-products were inventoried as well. For example: in FAOstat only the quantity of soybean oil is given. By using a fixed soybean oil to soybean meal yield ratio, the amount of soybean meal production can be quantified as well. An overview of additional inventoried processed commodities is given in Table 5-2.

Table 5-2: How inventoried products are quantified, production data and ratios used

Production data	Production inventoried	Ratio (Data/inventoried)	Comment / source:
Cashew nuts, with shell	Cashew nuts, shelled	0.25	Around 25% of the weight in shell. (FAO definition)
Almonds, with shell	Almonds, shelled	0.55	Around 55% of the weight in shell. (FAO definition)
Groundnuts, with shell	Groundnuts, shelled	0.7	For trade data, groundnuts in shell are converted at 70% and reported on a shelled basis. (FAO definition)
Hazelnuts, with shell	Hazelnuts, shelled	0.5	Around 50% of the weight in shell. (FAO definition)
Walnuts, with shell	Walnuts, shelled	0.53	Around 53% of the weight in shell. (FAO definition)
Brazil nuts, with shell	Brazil nuts, shelled	0.55	Around 55% of the weight in shell. (FAO definition)
Rice, paddy	Rice - total (Rice milled equivalent)	0.625	Industry average[9]
Oil, coconut (copra)	Cake, copra	0.604	Coconut copra meal (AFP process)
Oil, cottonseed	Cake, cottonseed	2.658	Feedprint: Cottonseed
Oil, groundnut	Cake, groundnuts	1.053	Feedprint: Peanut solvent crushing solvent extraction
Oil, linseed	Cake, linseed	1.829	Feedprint: linseed solvent extraction
Oil, maize	Cake, maize	1.871	Maize germ meal expeller, wet milling (AFP process)
Oil, palm kernel	Cake, palm kernel	1.128	Palm kernel expeller (AFP process)
Oil, rapeseed	Cake, rapeseed	1.390	Rapeseed meal, solvent (AFP process)
Oil, sesame	Cake, sesame seed	1.373	Feedprint: Sesame solvent extraction
Oil, soybean	Cake, soybeans	3.693	Soybean meal, solvent (AFP process)
Oil, sunflower	Cake, sunflower	1.250	Sunflower seed meal (AFP process)
Sugar beet	Sugar Raw Centrifugal	0.128	Sugar, from sugar beet (AFP process)
Sugar cane	Sugar Raw Centrifugal	0.132	Sugar, from sugar cane (AFP process)

[9] https://www.uaex.edu/publications/pdf/mp192/chapter-14.pdf

5.3 Transportation requirements for market mixes

Transportation requirements are largely based on the methodology applied in Feedprint (Vellinga et al., 2013b). In short, the transport model consists of two parts. First the distance within the country of origin (where the crop is cultivated) is estimated, it is assumed that the crops are transported from cultivation areas to central collection hubs. From there, the crops are subsequently transported to the country of the market mix.

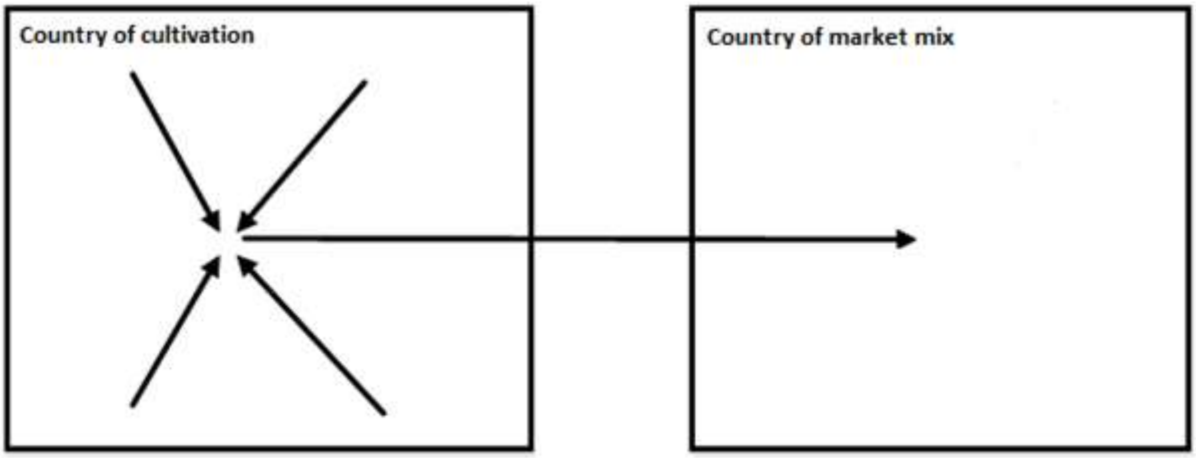


Figure 5-2: Generic transport model from a central hub in land of cultivation to the market location within a specific country.

5.3.1 Data collection

The transport model of Feedprint (Vellinga et al., 2013b) has been used as a basis but has been updated and extended to cover all relevant transport flows for new cultivation countries. The transport distance has been estimated using the following principles:

Domestic distances based on transport mix from EuroStat (tkm travelled per mode for domestic transport tasks).

Distance between EU countries based on country midpoint to midpoint, using international transport mode mix from EuroStat

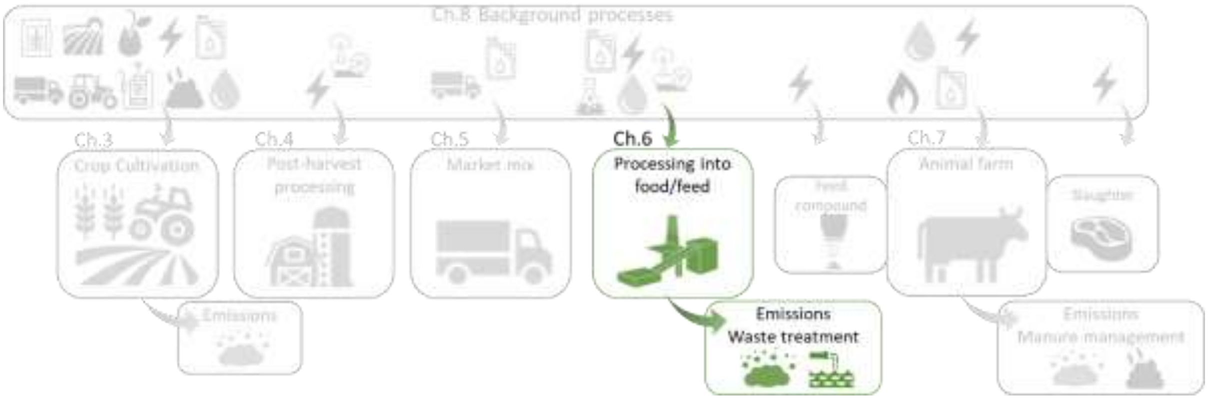
Distance between European countries and countries outside Europe based on transoceanic freight distances using http://www.searates.com/reference/portdistance/

Distance in US based on GREET model assumption (50 miles = 80 km by truck from field to processor)

5.3.2 Transport of crops from cultivation areas to central hubs

Within the EU, EuroStat (European Commission, 2014) provides detailed statistics for average transport modes and distances for goods within a country. These data have been used as proxy for the average distance and mode of transport of crops. For the United states, the average distance and transport mix is based on the GREET model (Elgowainy et al., 2013). For countries outside the EU, distances are based on literature when available or expert judgment based on past experience (these distances have often been carried over from the Feedprint method (Vellinga et al., 2013b).

6 Processing of crops and animal products into feed and food ingredients



6.1 Introduction and reader's guidance

Table 6-1 is a simplified list of processed feed and food products, and the related data source that formed the basis of the inventory. Average process specific data were derived for these processes, often the regional average of the EU or USA. Differences between countries are caused by the connection to different background data for electricity and heat.

Table 6-1 Simplified list of processed feed and food products, and the related data source that formed the basis of the inventory.

Crop/animal products	Feed products	Food products	Source and original region of data
Animal products	Fat from animals Greaves meal Animal meal Blood meal	Food grade fat Cream (full fat)	(van Zeist et al., 2012a) (European Commission, 2005) (Safriet, 1995)
	Fish meal Fish oil		(van Zeist et al., 2012a)
	Milk powder (skimmed) Milk powder (full fat)	Cream (skimmed) Milk powder (skimmed) Milk powder (full fat) Milk standardized (full fat) Milk standardized (skimmed) Cheese (Gouda 48+)	(van Zeist et al., 2012a) (Sheane et al., 2011)
Cereal products	Brewer's grains		(van Zeist et al., 2012c)
	Maize germ meal expeller Maize germ meal extracted Maize gluten meal dried Maize gluten meal wet Maize gluten feed dried Maize gluten feed wet Maize solubles Maize starch dried	Maize flour Maize starch Maize germ oil	(van Zeist et al., 2012c, 2012f) (Eijk & Koot, 2005) (Bolade, 2009) (Bechtel et al., 1999)
	Oat grain peeled Oat husk meal Oat mill feed high grade	Oat grain peeled	(van Zeist et al., 2012c)

Crop/animal products	Feed products	Food products	Source and original region of data
	Rye middlings	Rye flour	(van Zeist et al., 2012c)
	Wheat bran Wheat germ Wheat gluten feed Wheat gluten meal Wheat middlings & feed Wheat starch slurry	Wheat starch Wheat flour	(van Zeist et al., 2012c, 2012f)
	Rice bran meal Rice feed meal Rice husk meal	White rice Brown rice Rice brokens Refined rice bran oil	(Goyal, S. et al. 2012) (Blengini and Busto, 2009) (Roy, P. et al 2007)
Oilseed products	Coconut copra meal	Refined coconut oil	(van Zeist et al., 2012b)
	Palm kernel expeller Palm kernels Crude palm oil Fatty acid distillates	Refined palm oil Refined palm kernel oil	(van Zeist et al., 2012b)
	Rapeseed expeller Rapeseed meal	Refined rapeseed oil	(van Zeist et al., 2012b) ((S&T)2 Consultants, 2010) (Schneider & Finkbeiner, 2013)
	Crude soybean oil Soybean protein-concentrate Soybean expeller Soybean hull Soybean lecithin Soybean meal Soybean okara Soybean, heat treated	Refined soybean oil Soybean protein-concentrate Soybean protein-isolate	(van Zeist et al., 2012b) (Sheehan, Camobrecco, Duffield, Graboski, & Shapouri, 1998) (OTI, 2010) (Schneider & Finkbeiner, 2013) (Veghel van, 2017)
	Sunflower seed dehulled Sunflower seed expelled dehulled Sunflower seed meal	Refined sunflower oil	(van Zeist et al., 2012b)
	Groundnut meal Crude peanut oil		(van Zeist et al., 2012b)
	Linseed expeller Linseed meal Crude linseed oil	Refined linseed oil	(van Zeist et al., 2012b)
Legume products	Broad bean hulls	Broad bean meal	(Broekema & Smale, 2011)
	Lupins fibre Lupins hull Lupins okara Lupins protein slurry	Lupins oil Lupins protein-concentrate Lupins protein-isolate	(Veghel van, 2017)
	Pea wet animal feed Pea starch-concentrate Pea slurry	Pea protein-isolate Pea protein-concentrate Pea starch slurry	(Veghel van, 2017)
Roots & tubers products	Cassava root dried Cassava peel Cassava pomace (fibrous residue)	Tapioca starch	(Chavalparit & Ongwandee, 2009) (van Zeist et al., 2012d)

Crop/animal products	Feed products	Food products	Source and original region of data
	Potato juice concentrated Potato pulp pressed fresh + silage Potato pulp dried	Potato protein Potato starch dried	(van Zeist et al., 2012f)
Fruit and vegetable products	Citrus pulp dried		(van Zeist et al., 2012d)
Sugar products	Sugar beet molasses Sugar beet pulp wet Sugar beet pulp dried	Sugar from sugar beet	(van Zeist et al., 2012e) (Klenk, Landquist, & Ruiz de Imaña, 2012)
	Sugar cane molasses	Sugar from sugar cane	(van Zeist et al., 2012e)

6.1.1 Waste in processing

Not all waste flows are included in the processing LCIs. There are several reasons why some minor waste flows have been omitted in the following case:

- Not a lot of information is available from literature on the quantity and type
- The fate of these flows is not known (to wastewater, mixed into feed streams, recycled, as soil improver or other waste), and
- The flows are usually small and fall well below the cut-off of 5%.

In Agri-footprint 5.0 the bio-waste flows that were not recirculated in the process has been modelled as wastewater treated if liquid waste and landfilled if solid waste. Even if the fates are not always known, these assumptions help the user in visualizing the complete mass balance of the process.

6.1.2 Water use in processing

Some of the original processing LCI's were taken from Feedprint in which water use was not accounted for as an input. The original data sources used in the Feedprint study often contain water use data. These were used as the primary data source for water use in processing. If data could not be found in these sources, other data from literature were used. Sometimes, no water use data for a specific crop/processing combination could be found. In that case, water use data from an analogous process for a different crop were used as a proxy. The water use sources for a specific process are indicated in the next chapters.

Water use is reported in Agri-footprint as "Water, unspecified natural origin" (sub-compartment 'in water'), with a specific country suffix, making the elementary flow region specific (e.g. "Water, unspecified natural origin, FR" – in water). Hereby the user can perform water stress related impact studies.

6.1.3 Energy use in processing

Three system processes based on ELCD database are used as energy input. Electricity use (Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System) is country specific, while use of process steam from natural gas (Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S System) and from heavy fuel oil (Process steam from heavy fuel oil, heat plant, consumption mix, at plant, MJ EU-27 S System - Copied from ELCD) are based EU averages.

6.1.4 Auxiliary material/other ingredients in processing

Several other inputs are used in processing LCI. For some of the auxiliary material the production process is modelled in AFP database. The description of these can be found in chapter 8.3. Other auxiliary materials and input used are based on ELCD or USLCI database (system processes) (Table 6-2).

Table 6-2 Auxiliary material used in various processes, based on background system processes.

Auxiliary material/Other ingredients	Process
Sodium chloride, production mix, at plant, dissolved RER System	Cheese production
Sulphur, from crude oil, consumption mix, at refinery, elemental sulphur EU-15 S System	Cassava, sugar beet and sugar cane processing
Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S System	Sugar beet processing
White mineral oil, at plant/RNA System	Soybean crushing
Nitrogen, via cryogenic air separation, production mix, at plant, gaseous EU-27 S System	Various oil refining

6.2 Animal products

6.2.1 Meat co-products

Processing of meat co-products into blood meal, greaves meal, food grade fat, fat from animals and animal meal is based on Feedprint (van Zeist et al., 2012a) and other literature sources (European Commission, 2005; Safriet, 1995).

6.2.2 Fish co-products

Processing of landed fish and offal, from fishery into fish oil and meal is based on Feedprint (van Zeist et al., 2012a) and other literature sources (Jespersen, Christiansen, & Hummelmose, 2000; Olesen & Nielsen, 2000; Pelletier, 2006; Pelletier et al., 2009).

6.2.3 Dairy products

Milk is standardized into full fat milk and skimmed milk. A co-product of standardized milk is cream. KWA Bedrijfsadviseurs was approached to supply a complete dataset from Dutch dairy industry with mass balances and energy use. Milk standardization was modelled after information provided by KWA Bedrijfsadviseurs in 2011.

Cheese is produced from full fat standardized full fat milk. A co-product of cheese production is liquid whey, which is used as an animal feed in pig husbandry or dried and processed into food products. The composition of the products was based on van Zeist et al. (2012a), the energy use is based on Sheane et al. (2011).

For economic allocation, the financial revenue of cheese and liquid whey was determined. Liquid whey has very low financial revenue when not dried because of the high water content, and it will be used to feed pigs. Dried whey can be used in various food products to enhance nutritional properties. Based on expert judgement, the price of cheese and liquid whey is determined:

- Cheese: 3,40 €/kg
- Liquid whey: 6,50 €/ton liquid whey

This means that 98.7% of the environmental impact of cheese processing is allocated to cheese, and 1.3% of the environmental impact of cheese processing is allocated to liquid whey.

Drying of liquid whey was modelled based on Ramirez, Patel, & Blok (2004). The composition of the products was based on van Zeist et al. (2012a).

6.3 Cereal products

6.3.1 Wet milling (maize, wheat)

Wet milling of maize is characterized by many intermediate steps and different type of food/feed co-products (Figure 6-1). The overall process is based on Feedprint (van Zeist et al., 2012f).

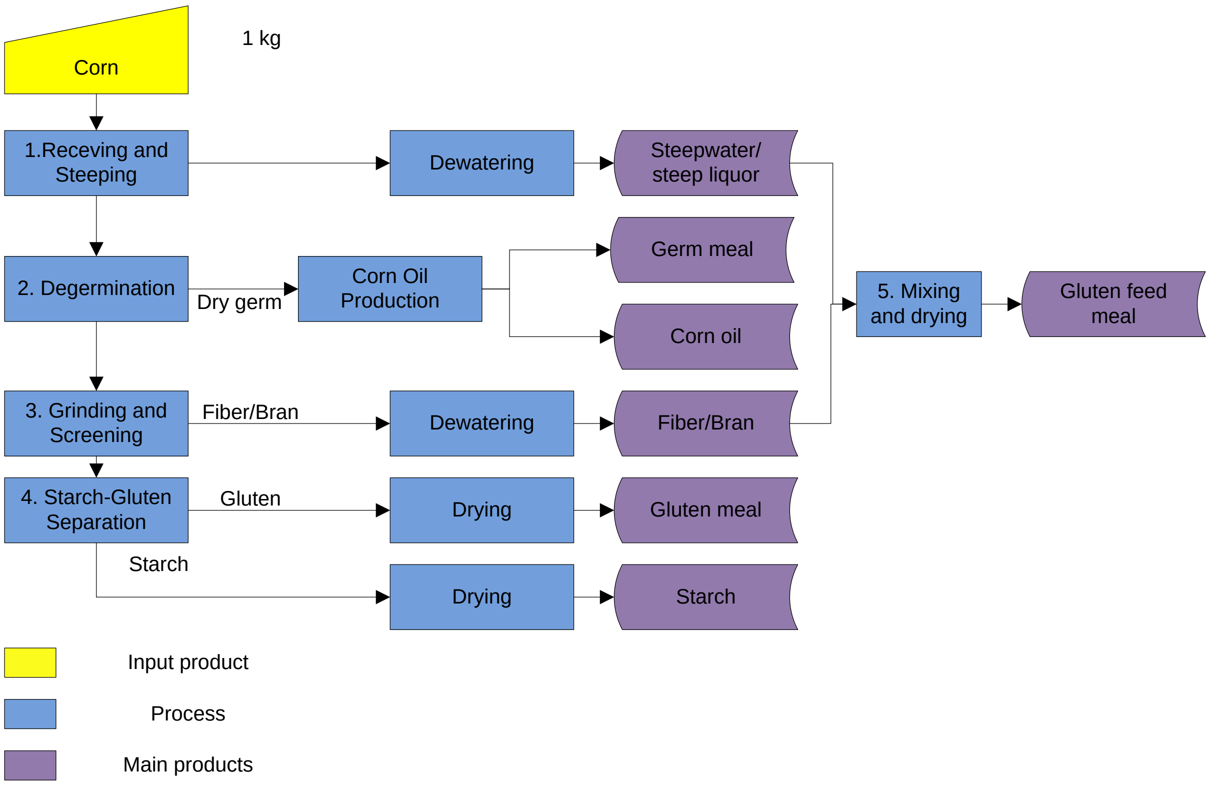


Figure 6-1 Wet milling of maize (van Zeist et al., 2012f).

While in maize all the sub steps are modelled, the wet milling of wheat is aggregated in one single LCI. The overall process is also based on Feedprint (van Zeist et al., 2012f). Water use for wet milling was not included in Feedprint, therefore the value was based on a report from European Commission (2006). For the water use in the corn oil production subs step (maize germ oil), rapeseed crushing (solvent) water use was used as proxy.

6.3.2 Dry milling (maize, wheat, rye, oat)

The mass balance for the dry milling of maize was based on Bolade (2009), which describes maize dry milling options in Africa. This publication is not detailed enough to include all co-products from dry milling of maize, thus the simplified mass balance gives flour and a generic by-products amount stemming from maize dry milling. Energy requirements for the dry milling of maize could have been based on Li, Biswas, & Ehrhard (n.d.) and Mei, Dudukovic, Evans, & Carpenter (2006). This is a publication of ethanol production from maize in a North American region, so the energy consumption is most likely underestimated, since dry milling to meal/flour takes several milling rounds, which is not required for producing ethanol. Besides, energy requirements vary greater than mass balances between regions. So, for dry milling of maize in EU countries, the decision was made to apply the energy requirements for wheat dry milling in Europe by Eijk & Koot (2005) for the dry milling of maize in Europe, as this inventory is more representative of the technology in scope (dry milling of maize for food purposes).

Dry milling of rye grain, wheat grain and oat grain are based on Feedprint (van Zeist et al., 2012c). Water use in dry milling is based on Nielsen & Nielsen (2001).

6.3.3 Dry milling (rice)

This process describes the production of brown rice (rice without husks) and rice husks from a rice dry milling process in China (Figure 6-2). Rice husk meal is typically used as animal feed. Traditionally, the process of de-husking was done manually, but nowadays the de-husking machine consists of a pair of rubber-lined rollers which are mounted in an enclosed chamber. As the rice passes through these rollers the husks are removed by friction leaving the paddy intact.

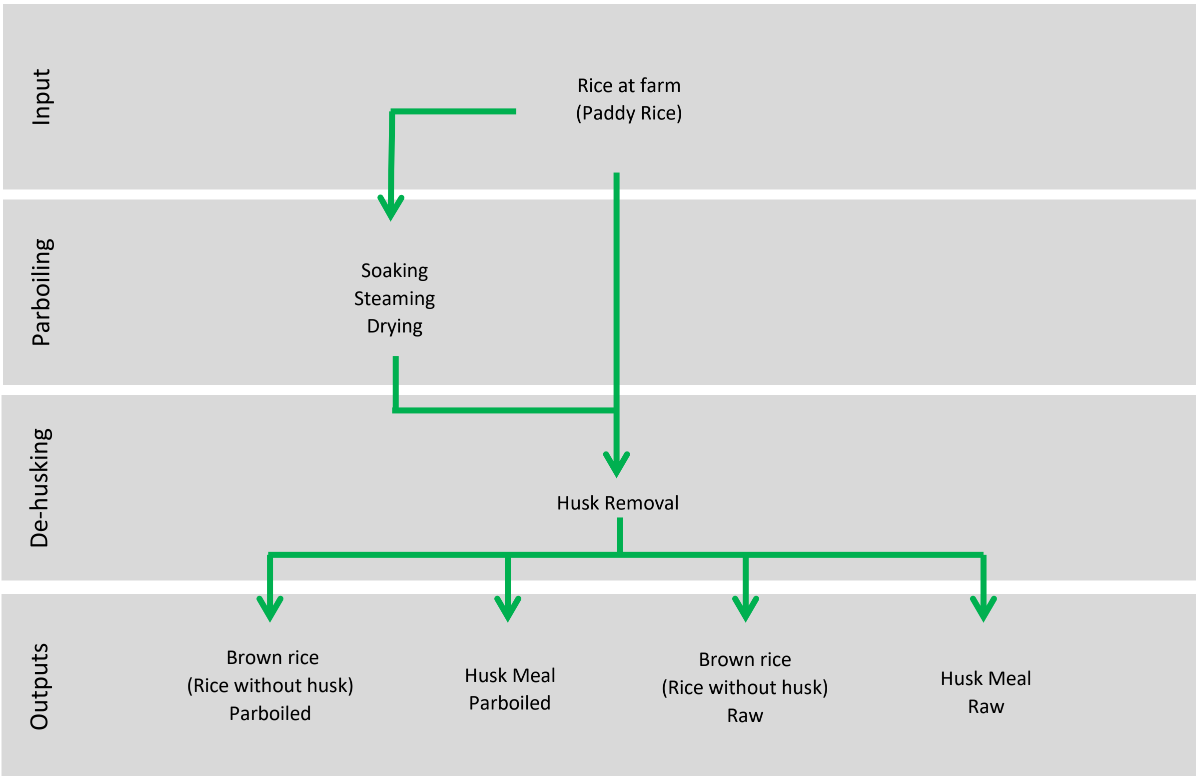


Figure 6-2: Diagram describing the process of production of rice without husks and rice husks from a rice dry milling process.

The parboiling process consists on soaking, partially boiling and drying the rice in the husk. Parboiling before de-hulling is optional, although it is estimated that half of the paddy rice is parboiled before processing. The advantages of parboiling are a reduction on grain breaking and improved nutritional content due to the fixation of thiamine to the rice endosperm. Weight changes or losses during the parboiling process were not taken into account.

These process steps are aggregated into a single process in the inventory and include the use of electricity and steam. The mass balance of the process is based on data from IRRI (2015a) (but mass of hulls and white rice is combined into a single output). Data on inventory inputs were taken from regional data (Goyal, Jogdand, & Agrawal, 2012). To ensure the data consistency the data was compared to other publicly reported data for milling (Blengini & Busto, 2009; Roy & et al., 2007). The data showed good agreement with the referenced studies as it showed similar input/output ratios. Water use in dry milling are based on Nielsen & Nielsen (2001).

Another process describes the production of white rice, rice husks, rice bran and rice brokens from a rice dry milling process in China (Figure 6-3). The process starts with paddy rice, followed by de-husking and the milling process. Parboiling before de-hulling is optional, although it is estimated that half of the paddy rice is parboiled before processing. The advantages of parboiling are a reduction on grain breaking (less brokens) and improved nutritional content due to the fixation of thiamine to the rice endosperm.

The de-husking machines consists of a pair of rubber-lined rollers which are mounted in an enclosed chamber, as the rice passes through these rollers the husks are removed by friction leaving the paddy intact. The milling encompasses polishing to remove the bran and grading white rice and broken. These process steps are aggregated into a single process in the inventory, and it includes the use of electricity and steam. The mass balance of the process is based on data from IRRI (2015b) (but mass of hulls and white rice is combined into a single output). Data on inventory inputs are taken from regional data (Goyal et al., 2012), and compared to other publicly reported data for milling (Blengini & Busto, 2009; Roy & et al., 2007). Water use in dry milling are based on Nielsen & Nielsen (2001).

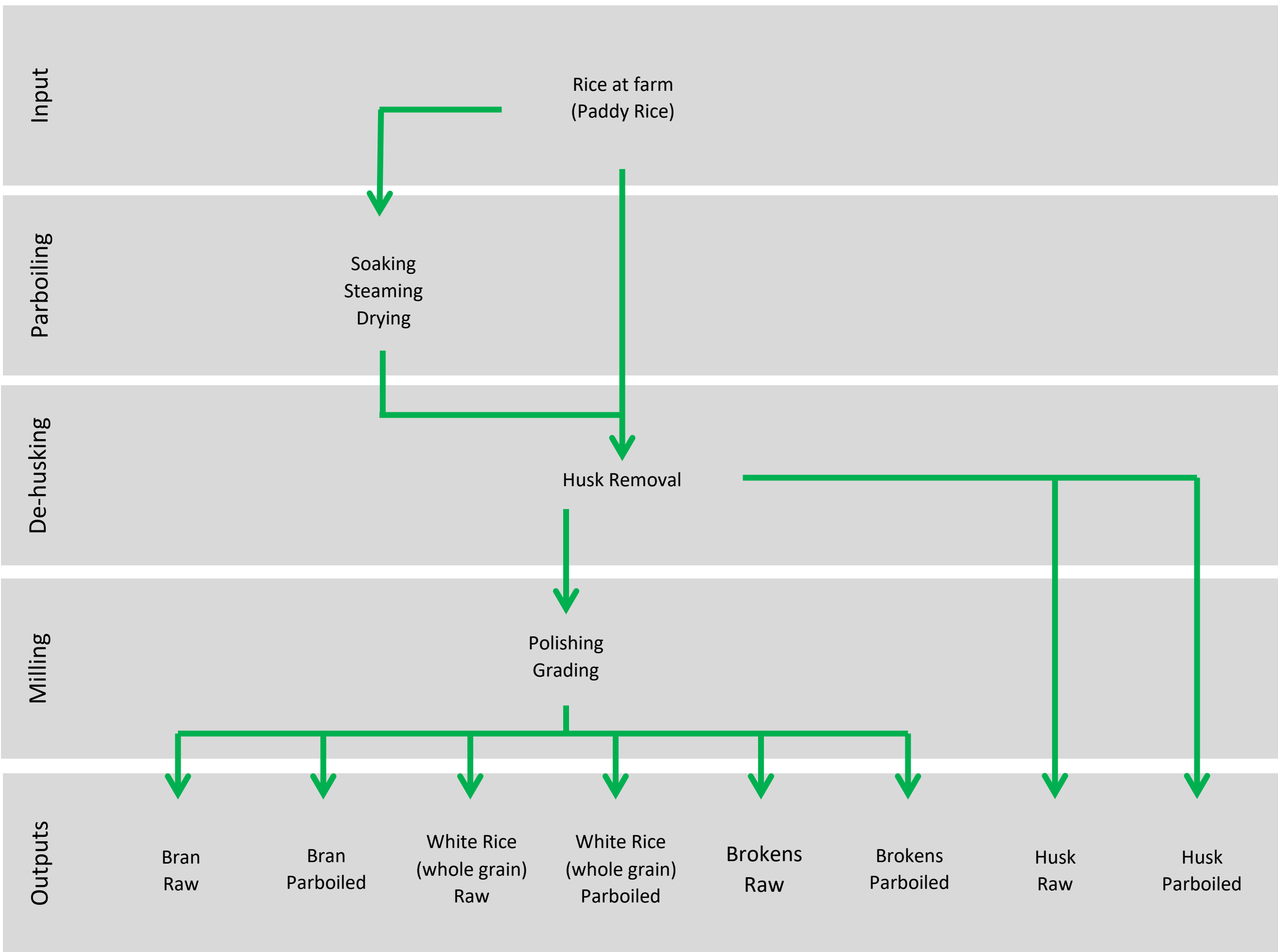


Figure 6-3: Diagram describing the process of production of white rice, rice husks, rice bran and rice brokens from a rice dry milling process in China.

6.4 Oilseed products

The partial and full dehulling (pre-processing) of sunflower seed is based on the Feedprint report (van Zeist et al., 2012b). The soybean heat treatment are based on Sheehan et al. (1998).

6.4.1 Crushing

The crushing of oil palm fruit (pressing), oil palm kernel (pressing), sunflower (solvent and pressing), groundnuts (solvent), coconut (pressing) and linseed (pressing and solvent) are based on Feedprint (van Zeist et al., 2012b).

The crushing of sunflower was updated compared to previous versions. Previously the hulls were considered as a waste flow landfilled that resulted in a certain amount of impact. In reality, the fate of sunflower hulls is very case-specific therefore they were considered as co-product assuming no value in case of economic allocation. When data will be available on the fate and price of sunflower hulls, it will be possible to update the process.

For the inventory of non-European crushing of soybean (pressing and solvent) and rapeseed (pressing and solvent) the Feedprint documentation was used (van Zeist et al., 2012b), for Europe a FEDIOL report was used as the main data source (Schneider & Finkbeiner, 2013).

FEDIOL represents the European Vegetable Oil and Protein meal Industry. Its federation members (1) purchase, store and transport oilseeds and vegetable oils; (2) process oilseeds into meals and crude oils, (3) refine and transform crude vegetable oils and (4) sell oils in bulk and in bottles to the food, feed and energy markets and meals to the feed market.

FEDIOL commissioned TU Berlin to conduct an LCA of oilseed crushing and vegetable oil refining. The objectives of this study were the establishment of a valid database, relating to primary data from the industry, and the assessment of potential environmental impacts of oilseed crushing focusing on rape seed oil, soybean oil and palm oil. These objectives make this study (Schneider & Finkbeiner, 2013) a good reference for an LCI of the crushing of soybeans and rapeseed in countries in the EU. Primary data from FEDIOL member companies (with best possible accuracy) are collected regarding all relevant processes. The data relate to crushing of oilseeds (soybeans, rape seed) at production facilities located in Europe. In total, 85% of the oilseed crushing and oil refining capacity in Europe is covered by FEDIOL members. The data obtained from FEDIOL members are aggregated based on information from more than twenty sites and six different countries, covering between 85 and 90% of all FEDIOL activities. Hence, the sample can be seen as representative for Europe since the participating companies constitute a high share of overall European activity.

For the crushing of soybeans and rapeseed in the US, other data sources have been used. The main sources of data for crushing of soybean and rapeseed are OTI (2010), Sheehan et al. (1998) and (S&T)2 Consultants (2010). An important feature of the soybean crushing in the FEDIOL report is that no hulls are produced, since they are recirculated and incorporated in the meal. Furthermore, a small modification was applied: the soybean lecithin co-product was moved from crushing to soybean oil refining, since produced during degumming of the oil (typical step of oil refining).

For sunflower crushing (solvent) was assumed same water use as for rapeseed crushing (Schneider & Finkbeiner, 2013). For crushing through pressing no water use is assumed. Coconut crushing is also assumed dry, as currently most economic process. For palm kernel processing, no data is found but is assumed to be insignificant by Schmidt (2007).

6.4.2 Oil refining

Two literature sources have been used to model the refining of crude oil (Nilsson et al., 2010; Schneider & Finkbeiner, 2013). The refining efforts, auxiliary products required, and by-products depend on the type of vegetable oil.

Table 6-3: Process in- and outputs of oil refining

		Sunflower oil	Rapeseed oil	Soybean oil	Palm oil	Palm kernel oil
Literature source		(Nilsson et al., 2010)	(Schneider & Finkbeiner, 2013)			(Nilsson et al., 2010)
Inputs						
Crude oil	kg	1,046.46	1,032	1,038	1,080	1,068.8
Water	Kg	0	500	540	130	0
Bleaching earth	Kg	3.03	4.0	5.4	12	4.3
Phosphoric acid (85%)	Kg	0	0.7	1.0	0.85	0
Sulfuric acid (96%)	Kg	0	2.0	2.0	0	0
Nitrogen	Kg	0	0.5	0	1.5	0
Activated carbon	Kg	5.05	0.2	0.2	0	0
Sodium hydroxide	kg	0	3.0	2.8	0	0
Steam	Kg	266	170	225	115	214.67
Electricity	kWh	54.8	27	40	29	48.07
Diesel fuel	Kg	8.02	0	0	0	8.53
Outputs						
Refined oil	Kg	1,000	1,000	1,000	1,000	1,000
By-products	kg	37.95	20	23	70	67.2

For some less commonly used oils, no data were available. Therefore, the average of sunflower, rapeseed and soybean oil processing was used. Palm oil processing was not considered applicable as proxy, due to its high free fatty acid content and high levels of other substances (carotenes and other impurities) not commonly found in other vegetable oil types.

Table 6-4: Average process in and outputs of oil refining of maize germ oil, rice bran oil, coconut oil, linseed oil.

Inputs		
Crude oil	kg	1,039
Water	Kg	347
Bleaching earth	Kg	4.14
Phosphoric acid (85%)	Kg	0.57
Sulfuric acid (96%)	Kg	1.33
Nitrogen	Kg	0.17
Activated carbon	Kg	1.81
Sodium hydroxide	Kg	1.93
Steam	Kg	220
Electricity	kWh	40.6
Diesel fuel	Kg	2.67
Outputs		
Refined oil	Kg	1,000
By-products	kg	27.0

Table 6-5 presents the key parameters that were used to determine the allocation fractions for the co-products of rapeseed, soybean and palm oil refining. For the other refined oils, it is assumed that the by-products have the same properties as rapeseed and soybean oil (i.e. same LHV and average of the economic values for co-products) see Table 6-6.

Table 6-5: Key parameters required for mass, energy and economic allocation.

		Rapeseed oil	Soybean oil	Palm oil	Data source
Mass allocation:					
Dry matter refined oil	g/kg	1,000	1,000	1,000	(Schneider & Finkbeiner, 2013)
Dry matter soap stock	g/kg	1,000	1,000	-	
Dry matter fatty acid distillate	g/kg	-	-	1,000	
Energy allocation:					
LHV refined oil	MJ/kg	37	37	37	(Schneider & Finkbeiner, 2013)
LHV soap stock	MJ/kg	20	20	-	
LHV fatty acid distillate	MJ/kg	-	-	30	
Economic allocation:					
Value refined oil	€/kg	0.843	0.809	0.803	(Schneider & Finkbeiner, 2013)
Value soap stock	€/kg	0.200	0.350	-	
Value fatty acid distillate	€/kg	-	-	0.632	

Table 6-6: Estimated key parameters required for mass, energy and economic allocation for other refined oils and soap stock.

		Other refined oil	Comment
Mass allocation:			Applies to maize germ oil, rice bran oil, coconut oil, palm kernel oil and sunflower oil
Dry matter refined oil	g/kg	1,000	
Dry matter soap stock	g/kg	1,000	
Energy allocation:			Based on values for rapeseed and soybean oil
LHV refined oil	MJ/kg	37	
LHV soap stock	MJ/kg	20	
Economic allocation:			Based on values for rapeseed and soybean oil
Value refined oil	€/kg	0.826	
Value soap stock	€/kg	0.275	

6.5 Pulse products

Broad beans crushing into meal and hull was based on Broekema & Smale (2011). Lupins, pea and soybean processing into protein-concentrate and protein-isolate was based on the internship report by van Veghel (2017) at Blonk Consultants. The LCAs are based on literature and company communication. When possible, the literature data were verified by expert/industries. Table 6-7 shows the dry matter (DM) content, prices and gross energy (GE) content used for allocation purposes for all pulse outputs.

Table 6-7: Key parameters for mass, energy and economic allocation.

Output	DM content (g/kg)	GE content (MJ/kg)	Price (€/ton)
Broad bean, meal	900	18.0	550
Broad bean, hulls	900	9.2	130
Lupins fibre	600	9	495
Lupins hull	960	10.6	285
Lupins okara	410	3	140
Lupins protein slurry	35	0.3	489
Lupins oil	100	39.1	759
Lupins protein-concentrate	900	19.7	1600
Lupins protein-isolate	900	19.7	2785
Pea wet animal feed	220	5.5	46
Pea starch-concentrate	905	16.3	495
Pea slurry	330	3	35
Pea protein-isolate	900	17	3500
Pea protein-concentrate	905	119.7	1600
Pea starch slurry	400	3	274
Soybean okara	410	3	140
Soybean slurry	110	0.3	372
Soybean fines	910	9	313
Soybean molasses	600	11.2	35
Soybean protein-concentrate	930	19.7	2000
Soybean protein-isolate	950	19.7	4350

6.5.1 Pulse protein-concentrates

The protein-concentrates production a dry fractionation/air classification for pea and lupin, while a traditional ethanol water extraction for soybean. While the latter is an established industrial process, the dry fractionations of legume is still a new product. Still, the growing interest in meat substitutes could potentially boost these markets.

Figure 6-4, Figure 6-5 and Figure 6-6 shows the graph used to extrapolate the data for LCIs.

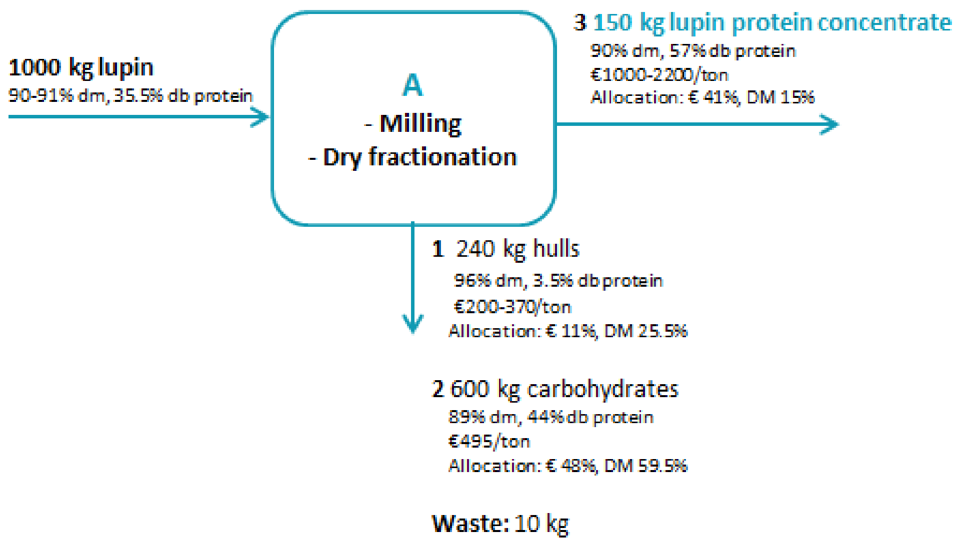


Figure 6-4 Lupin protein-concentrate production process (Veghel van, 2017).

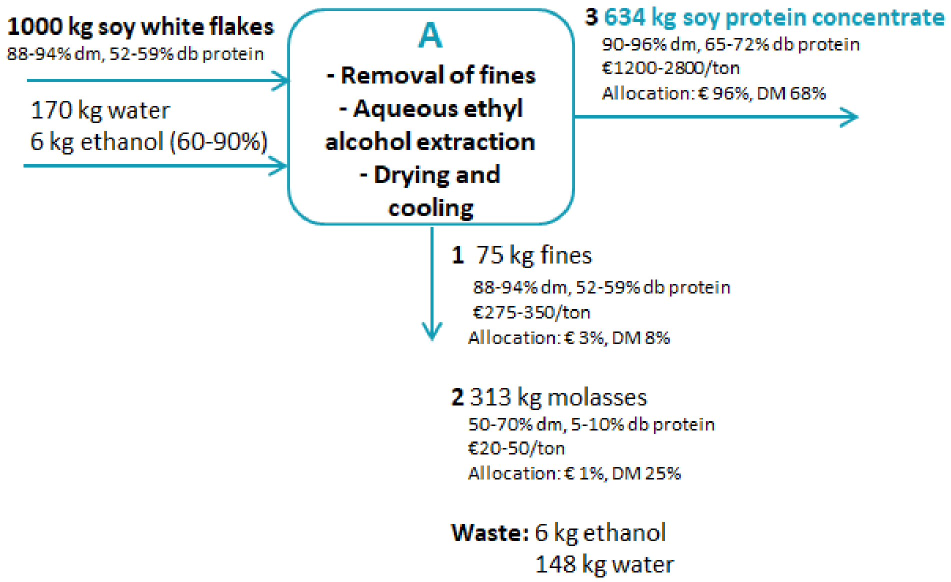


Figure 6-5 Soy protein-concentrate production process (Veghel van, 2017).

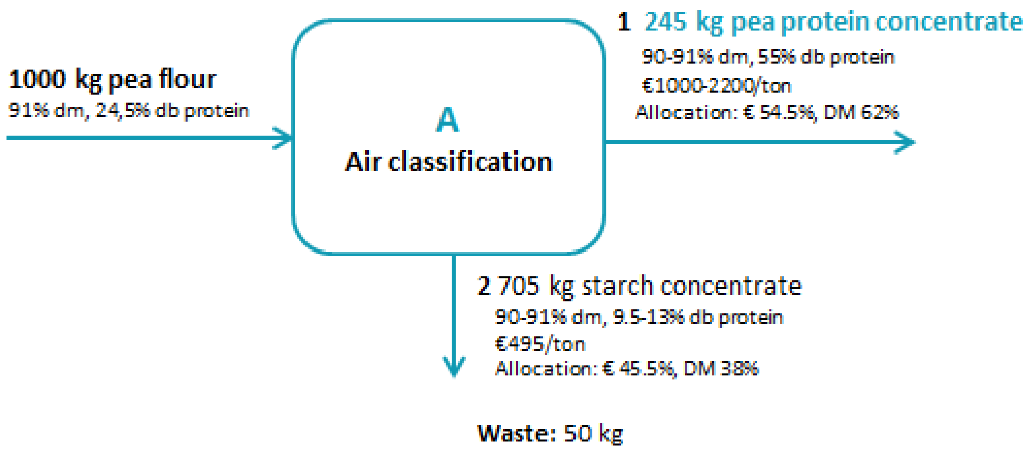


Figure 6-6 Pea protein-concentrate production process (Veghel van, 2017).

6.5.2 Pulse protein isolates

Isolates are produced trough a two steps process. Soybean isolate processing is a wet treatment on soybean meal, also called white flakes (Figure 6-7). Through acid and basic treatment, the proteins are separated. The second step is spray drying of the protein slurry. Same process is considered for lupin protein-isolate (Figure 6-8).

Production of pea protein isolate is shown in Figure 6-9 and occurred through separation of starch by hydrocyclones, followed by separation of fibres by a decanter centrifuge. After which precipitation of the soluble proteins occurred upon addition of phosphoric acid. These precipitated proteins were neutralized by sodium hydroxide and then spray dried. In AFP has been assumed as input directly pea, dried, since no data were available on pea milling into flour.

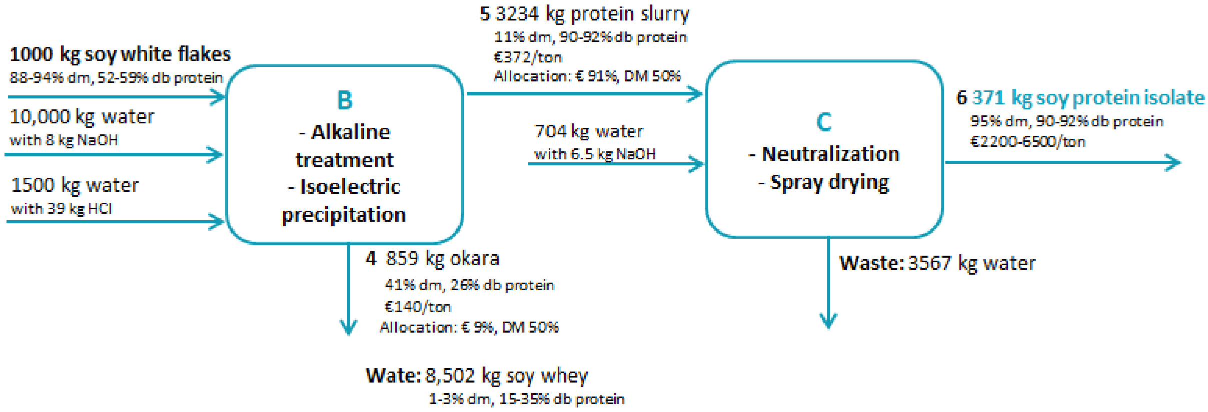


Figure 6-7 Soy protein-isolate production process (Veghel van, 2017).

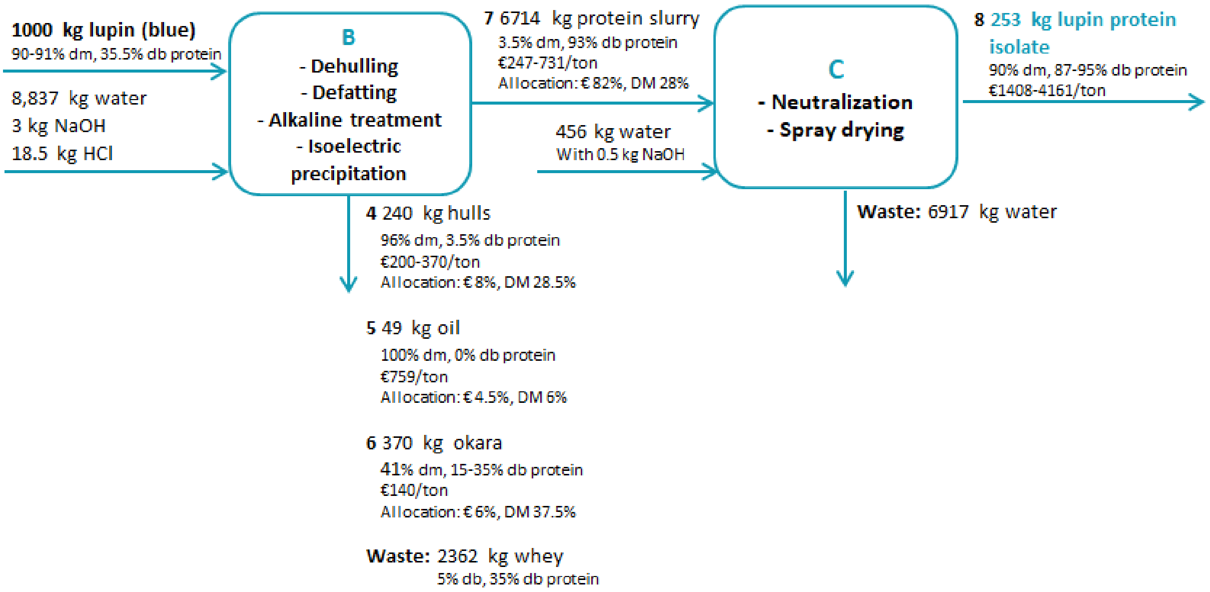


Figure 6-8 Lupin protein-isolate production process (Veghel van, 2017).

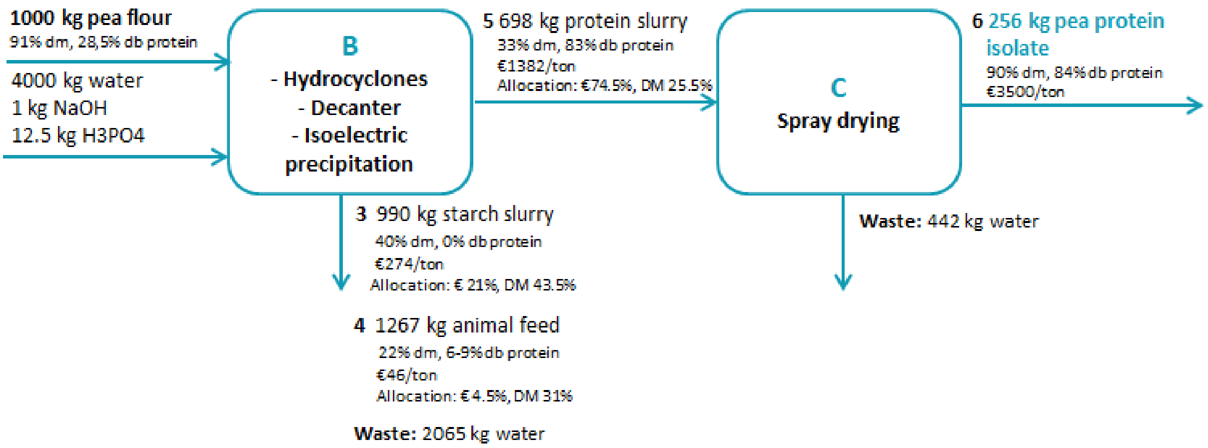


Figure 6-9 Pea protein-isolate production process (Veghel van, 2017).

6.6 Roots & tuber products

The potato wet milling into protein, juice concentrated, pulp pressed and dried starch is based on Feedprint (van Zeist et al., 2012f) and is aggregated in one LCI. Water use is based on European Commission (2006).

Cassava root processing was included in the original inventory of Feedprint, but this process did not take into account the use of co-products. When co-products like peels and fibrous residues (e.g. pomace) are not used, it results in heavy water pollution as it generates large amounts of solid waste and wastewater with high organic content. Based on literature, it is known that co-products are sold as animal feed at some plants. Because of this, two tapioca starch production processes are now included in Agri-footprint:

- Tapioca starch, from processing with use of co-products
- Tapioca starch, from processing without use of co-products

Both inventories are based on Chavalparit & Ongwandee (2009). The energy and sulfur are not included in the tables of this paragraph but are identical to the amounts mentioned in Chavalparit & Ongwandee (2009). The amount of fibrous residue (mainly pomace) was adapted to 15% of the cassava root because it can be up to 17% of the tuber (Feedipedia, 2014).

19.1 m3 of wastewater is generated to produce 1 tonne of tapioca starch output. This is identical to 454 kg of wastewater per tonne of cassava root input. The amount of peels is subtracted (454 kg – 90 kg) from the wastewater because peels are used as feed and do not end up in the wastewater. The pomace will end up in the wastewater, so the wastewater amount increased (454 kg + 150 kg).

A limitation of the tapioca starch inventories is that the wastewater process from ELCD has a European geographical coverage instead of the Thai situation. This probably does not fit the polluted wastewater output from tapioca starch processing. No specific Tapioca processing wastewater data or Thai wastewater processes exist.

6.7 Sugar products

6.7.1 Sugar from sugar beet

In 2012 the European Association of Sugar Producers (CEFS) published a report on the carbon footprint of EU sugar from sugar beets (Klenk et al., 2012). It is a detailed publication, containing the mass balance as well as energy requirements with a division between the sugar factory and the pulp drier. Average EU beet sugar factory emissions were calculated based on an EU-wide study conducted by ENTEC for the CEFS in 2010. The data covered the period 2005–2008.

6.7.2 Sugar from sugar cane

Several inputs are necessary during sugar cane processing. As Renouf et al. (2010) has the most transparent references this is the main data provider and the report of (ETPi, 2011) was used when the required data was not available in the article of Renouf et al.

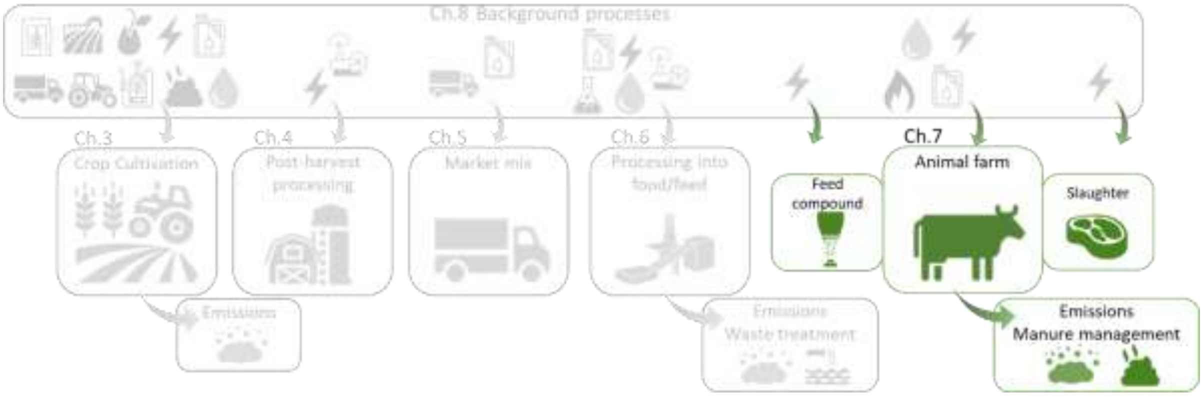
In the Feedprint data, the combustion of bagasse during sugar cane processing was not modelled (as the focus of the Feedprint project was on fossil carbon emissions). However, the emissions from bagasse combustion are included in Agri-footprint. When one tonne of sugarcane is processed, 280 kg of bagasse is created, which is combusted in the processing plant to provide heat and electricity. It is assumed that all the energy is used internally, and none is exported to a (heat or electricity) grid. The emissions are calculated from the emissions listed in Renouf et al. (2010) and by the Australian National Greenhouse Gas Inventory Committee (2007) and are provided in Table 6-8. Although it is possible for sugar mills to produce electricity as surplus for the market, there is no data on how common this practice is, so the assumption was made that no surplus electricity is delivered to the market.

Table 6-8: Gas emissions from combustion of 280 kg of bagasse 'as is' (wet-mass).

Emission	Unit	Quantity
Carbon dioxide, biogenic	kg	218.9
Methane, biogenic	g	23.9
Dinitrogen monoxide	g	10.5
Carbon monoxide, biogenic	kg	4.2
Sulfur dioxide	g	84.0
Particulates, < 10 um	g	134.4

Renouf, Pagan, & Wegener (2010) mention that the water evaporated from the cane is enough for what is needed. COD is described as 23 kg per 100 tonnes cane input. European Commission (2006) only notes that the water consumption is 'less' than sugar beet.

7 Animal farm systems



Please note that all farms are single enterprise, 'regular' animal production systems. Therefore, for example high welfare and organic systems were not taken into account.

7.1 Dairy farm system in the Netherlands

Raw milk is the main product that is produced on dairy farms. In addition, calves are produced (kept partly for herd replacement and partly sold to the veal industry), and unproductive cows are sent to slaughter. For this study, recent data for the average Dutch dairy farm have been used, see Table 7-1.

Table 7-1: Primary data sources for dairy farm parameters

Primary data sources	References	Parameters
Binternet	(Wageningen UR, 2015a)	On-farm energy consumption Herd size, slaughtered cows, sold calves Fertilizer application for roughage production Prices of raw milk, meat and calves.
CBS Statline	(CBS, 2015)	Herd size Ratio of other animal types to dairy cows
CBS	(CBS, 2011, CBS, 2008)	Milk yield Feed intake Nitrogen and phosphorous excretions Liquid manure production and time spent outside in the pasture
Dutch National Inventory Reports	(CBS, WUR, RIVM, & PBL, 2011) (National Institute for Public Health and the Environment, 2013)	Emissions of methane due to enteric fermentation.
IPCC guidelines	(IPCC, 2006b)	Emissions from livestock and manure management

The herd at the average Dutch dairy farm consists of about 82 dairy cows in 2011 (Table 7-2). Hardly any male animals are kept, while most female calves are kept and raised for herd replacement. Most of the male calves and a small part of the female calves which are not needed for herd replacement are sold shortly after birth to the veal industry. This means that 45 calves at an average dairy farm are sold each year. The dairy cows which are replaced (due to old age or injury) are slaughtered, which results in annual slaughtered live weight of 14,400 kg per year. Since the average milk yield per dairy cow in 2011 in the Netherlands is 8,063 kg per year, the annual milk yield for the average Dutch dairy farm is 661,972 kg per year.

Table 7-2: Herd size at the average Dutch dairy farm in 2011.

Type of animal	# animals
Female calves < 1 yr	30.0
Male calves < 1 yr	1.8
Female calves 1-2 yr	28.9
Male calves 1-2 yr	0.6
Dairy cows	82.1
Bulls	0.4
Heifers	4.4

Energy consumption at a dairy farm consists of electricity, diesel and natural gas, see Table 7-3 for the consumption of electricity and natural gas. The diesel consumption is incorporated in the cultivation and production of roughage.

Table 7-3: Energy consumption at the average Dutch dairy farm in 2011.

Energy source	Unit	Quantity
Electricity	kWh/farm/year	38,300
Natural gas	MJ/farm/year	37,980

The feed ration on the average Dutch dairy farm (CBS, 2010) is displayed in Table 7-4. The dairy cow ration consists of (1) concentrates, which contains a base concentrate and protein rich feed, (2) fresh grass, which they eat in pastures, grass silage and maize silage (see Table 7-5, Table 7-6, Table 7-7), and (3) wet by-products, like for instance brewers spent grain. For calves, the feed ration depends on their age. When calves are very young and stabled, they are fed with raw milk directly from the cows. The amount of milk fed to calves is 200 kg per calf for an 8-week period (CBS, 2010). This milk is produced by the cows but does not end up in the milk tank. Because the dairy farm is modelled as one animal system which produces calves, milk and meat, the milk which is fed to the calves is accounted for in this manner. The rest of the ration consists of concentrates, grass silage and maize silage. When calves are older, they spend relatively much time in the pasture where they eat mainly grass. The heifers were assumed to be fed the same ration as the female calves 1-2 years of age. On average the bulls are kept in the stable where they are fed concentrates and grass silage. Roughage is produced on the dairy farm, with a fraction of the manure which is excreted by the dairy cattle.

Table 7-4: Dry matter intake (DMI) of the animals on the average Dutch dairy farm in kg dry matter (DM) per animal per year.

Type of animal	Concentrates and protein-rich products	Fresh grass	Grass silage	Maize silage	Wet by-products
	Kg DM/animal/year				
Female calves < 1 yr	313.5	246.5	890	114	0
Male calves < 1 yr	275	420	575	575	0
Female calves 1-2 yr	83.5	1,182.5	1,666.5	77	0
Male calves 1-2 yr	297	0	2,956	0	0
Dairy cows	1,772	997	2,245.5	1,736	321
Bulls	297	0	2,956	0	0
Heifers	83.5	1,182.5	1,666.5	77	0
Dry matter content (%)	100%	16%	47%	30%	38%

Table 7-5: LCI for the cultivation of maize silage on the Dutch dairy farm.

Parameter	Unit	Value	Source	Comment
Yield of maize silage	kg/ha	46,478	(CBS, 2011)	Average of 1990, 2000, 2005 and 2010.
Dry matter content	%	30	(Wageningen UR, 2012a)	
Diesel requirement	MJ/ha	14,390.35	(Vellinga, Boer, & Marinussen, 2012)	
N-fertilizer	kg N/ha	47.5	Calculation according to manure policy	
P_2O_5 fertilizer	kg P_2O_5 /ha	7.1	Calculation according to manure policy	
Manure application	kg/ha	60975,61	Calculation according to manure policy	Equals to 250 kg N
Low density polyethylene	kg/ha	145.7	(Wageningen UR, 2012a)	For coverage of the silage

Table 7-6: LCI for the cultivation of fresh grass on the Dutch dairy farm.

Parameter	Unit	Value	Source	Comment
Yield of fresh grass	kg/ha	68,074	(CBS, 2011)	Average of 1990, 2000, 2005, 2010 and 2011.
Dry matter content	%	16	(Wageningen UR, 2012a)	
Diesel requirement	MJ/ha	4,268.2	(Vellinga et al., 2012)	
N-fertilizer	kg N/ha	197.5	Calculation according to manure policy	
P_2O_5 fertilizer	kg P_2O_5 /ha	22.1	Calculation according to manure policy	
Manure application	kg/ha	60975,61	Calculation according to manure policy	Equals to 250 kg N

Table 7-7: LCI for the production of grass silage from fresh grass.

Parameter	Unit	Value	Source	Comment
Grass silage	kg	0.34	(Wageningen UR, 2012a)	DM = 160 g/kg
Fresh grass	kg	1	(Wageningen UR, 2012a)	DM = 470 g/kg
Low density polyethylene	kg	0.001248	(Wageningen UR, 2012a)	For coverage of the silage

The contents of the compound feed and protein-rich products as well as the wet by-products have been based on the analysis of the yearly throughput of feed raw materials, specifically for dairy, of Agrifirm - the market leader in animal feed production in the Netherlands (Personal Communication, 2013). The energy consumption for the manufacturing of the compound feed is based on the Feedprint study. The ingredients are cultivated all over the world, and the Dutch mix consists of multiple cultivation countries for most ingredients. The wet by-products are fed as separate feeds, and do not need to be pelletized. Transport of feed ingredients (raw materials) to the factory is included in the raw materials. It is assumed that the feed is transported from the compound feed industry to the farm over 100 km by truck (see Table 7-8 and Table 7-9).

Table 7-8: LCI for the manufacturing of compound feed for dairy (base feed and protein-rich). The average dairy feed contains many ingredients. A dairy feed has been made with the top ingredients. The extra impact is estimated by not making a reference flow of 100 kg (because not 100% of the ingredients are accounted for) but for 93 kg.

Products		
Dairy compound feed (basic + protein) NL	Kg as fed	0.93
Materials/fuels		
Barley grain, market mix, at regional storage/NL	kg	0.010
Citrus pulp dried, consumption mix, at feed compound plant/NL	kg	0.085
Maize gluten meal, consumption mix, at feed compound plant/NL	kg	0.010
Maize, market mix, at regional storage/NL	kg	0.180
Palm kernel expeller, market mix, at regional storage/NL	kg	0.135
Rapeseed meal (solvent), market mix, at regional storage/NL	kg	0.170
Soybean meal (solvent), market mix, at regional storage/NL	kg	0.110
Soybean hulls, consumption mix, at feed compound plant/NL	kg	0.015
Molasses, market mix, at regional storage/NL	kg	0.040
Molasses, market mix, at regional storage/NL	kg	0.045
Triticale grain, market mix, at regional storage/NL	kg	0.025
Wheat gluten feed, consumption mix, at feed compound plant/NL	kg	0.035
Wheat bran, consumption mix, at feed compound plant/NL	kg	0.010
Triticale grain, market mix, at regional storage/NL	kg	0.060
Inputs from technosphere		
Heat, from resid. heating systems from NG, consumption mix, at consumer, temperature of 55°C EU-27 S	MJ	0.126
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S	MJ	0.293

*

Table 7-9: LCI for the mix of wet by-products fed to dairy cows. Dry matter: Handboek Melkveehouderij 2012, chapter 6, table 6.24

	Unit	Quantity	DM (g/kg)
Products			
Dairy wet by-product feed NL	Kg as fed	1.00	-
Materials/fuels			
Brewer's grains, at processing/NL	kg	0.18	220
Potato pulp pressed fresh+silage, consumption mix, at feed compound plant/NL	kg	0.14	160
Sugar beet pulp wet, market mix, at regional storage/NL	kg	0.23	220
Soybean meal (solvent), market mix, at regional storage/NL	kg	0.18	160
Rapeseed meal (solvent), market mix, at regional storage/NL	kg	0.09	880
Wheat grain, market mix, at regional storage/NL	kg	0.09	870
Maize, market mix, at regional storage/NL	kg	0.09	870

On the dairy farm, water is used for cleaning as well as for drinking water. Binternet (Wageningen UR, 2015a) reports on the amount of tap water which is used for cleaning: 1280 m^3 per farm per year. The amount of drinking water can be calculated based on the water intake via feed (Table 7-4) and the water needs (Table 7-10). The source of drinking water is commonly groundwater.

Table 7-10: Water needs for dairy cattle (Wageningen UR, 2012a)

Type of animal	Unit	Min	Max	Average
0-1yr	l/animal/day	5	30	17.5
1-2yr	l/animal/day	30	35	32.5
dry cow	l/animal/day	30	60	45
20kg milk/day	l/animal/day	70	100	45

The animals on the dairy farm excrete nitrogen, and phosphorous through manure and emit methane through enteric fermentation (Table 7-11). The methane emission factors for enteric fermentation for dairy cattle are calculated annually for several sub-categories (age) of dairy cattle. For mature dairy cattle, a country-specific method based on a Tier 3 methodology is followed (National Institute for Public Health and the Environment, 2013). The feed intake of dairy cattle, which is estimated from the energy requirement calculation used in The Netherlands, is the most important parameter in the calculation of the methane. The methane emission factor for enteric fermentation by young cattle is calculated by multiplying the Gross Energy intake by a methane conversion factor.

Table 7-11: Yearly excretion of nitrogen, phosphorous, manure, and methane emission due to enteric fermentation for each animal type on the average Dutch dairy farm.

Type of animal	N-excretion (kg N/ animal/year)	P_2O_5-excretion (kg P_2O_5 / animal/year)	Manure production (kg / animal/year)	Enteric fermentation (kg CH_4/ animal/year)
Female calves < 1 yr	34.8	9.4	5,000	29.1
Male calves < 1 yr	32.4	8.2	5,000	33.5
Female calves 1-2 yr	71.2	21.5	12,500	57
Male calves 1-2 yr	82.7	25.5	12,500	59.4
Dairy cows	127.6	40.6	26,000	128.7
Bulls	82.7	25.5	12,500	59.4
Heifers	71.3	21.5	12,500	57
Per kg of raw milk	**0.021**	**0.007**	**10.534**	**0.020**

The animals on an average Dutch dairy farm spend part of their time outside in the pasture, which has an effect on the ration of excretions dropped in the stable and on the pasture. Days spent on the pasture reflect full 24 hours spent outside. The calves up to 1 year of age are 37 days in the pasture (10% of the year). The calves between 1 and 2 years of age spend 88 days in the pasture (24% of the year). Dairy cows spend 35 days in the pasture (9.6% of the year).

The dairy farm produces three types of products which are sold: raw milk, meat and calves. The prices of raw milk, meat and calves for economic allocation were based on 5 year averages from Binternet (2007-2011) (Wageningen UR, 2015a). The average price for raw milk is €0.339 per liter. The average price of meat is €0.888 per kg. The average price per calf is €140.00. Based on the revenue for milk, meat and calves 92.2% of the environmental impact is allocated to raw milk, 5.2% to meat, and 2.6% to calves. The parameters in Table 7-12 can be used to calculate the allocation fractions for the physical allocation approaches: mass and gross energy.

Table 7-12: Parameters for physical allocation on the dairy farm.

Parameter	Unit	Value	Source	Comment
DM content milk	%	13.4		Raw milk contains 86.6% of water
DM content cows & calves	%	42.6	(Blonk, Alvarado, & De Schryver, 2007)	Excluding stomach content.
Energy content of milk	MJ/kg	3.3351		Raw milk contains: Lactose – 4.55% Protein – 3.45% Fat – 4.4%
Energy content of cows and calves	MJ/kg	11.28	(Blonk et al., 2007)	

The amount of peat land used on the dairy farm is another factor that affects the environmental impact of raw milk. In the Netherlands, dairy cattle often graze on peat lands, resulting in CO_2 and N_2O emissions due to peat oxidation and soil organic carbon losses caused by managed drainage. The share of peat land on an average Dutch dairy farm was assumed equal to the amount of peat land used for agricultural purposes in the Netherlands relative to the total amount of land used for agricultural purposes. The NIR reports that the amount of peat land used for agricultural purposes is 223,000 hectares (NIR, 2012). CBS Statline (CBS, 2015) reports that the total amount of land used for agricultural purposes is approximately 1,842,000 hectares. When assumed that the share of peat land on an average Dutch dairy farm was equal to the amount of peat land used for agricultural purposes in the Netherlands the estimate for the percentage of land for dairy farming that is peat land is 12.1%.

The N_2O and CO_2 emissions of peat land are calculated based on IPCC (2006c).

Another physical allocation method is recommended by the International Dairy Federation (IDF) in their LCA guide (IDF, 2010). This method reflects the underlying use of feed energy by the dairy cows and the physiological feed requirements of the animal to produce milk and meat. For the dairy system in Agri-footprint this leads to the following allocation fractions:

- Raw milk: 85.95%
- Meat: 12.35%
- Calves: 1.70%

This allocation method was pre-modelled in previous versions of Agri-footprint, but due to the fundamentally different allocation compared to the rest of the database it was set to 'obsolete'.

7.2 Irish Beef

The Irish beef system is based on a study by Casey & Holden (2006). In the Irish beef system, beef is produced; It is not a dairy system. In this system, beef calves are primarily fed on grass in pasture for a large part of the year (214 days), and grass silage and compound feed in stable (151 days). Calves are weaned after approximately 6 months; therefore, no additional feed is required for the first 6 months. The feed regime is listed in Table 7-13, and generic farming parameters in Table 7-14. Table 7-15 lists the feed intake over the whole lifetime of a beef animal as described in the study, and Table 7-16 details the composition of the compound feed. The meat calves are slaughtered after two years. However, the dietary requirements of cows that produce new calves are not mentioned in the study. Therefore, the feed ration intake of the calves in their second year has been used as a proxy for the feed intake of cows that are kept for breeding and herd replacement. The feed intake from Table 7-15 has been linearly scaled to the time spent in pasture and indoors (e.g. total time in pasture = 244 days, therefore grass intake in 30 days in year 1 is 30/244*12,355= 1,519 kg).

A herd consists of 20 cows, giving birth to 18 calves (a birth rate of 90%). 3 cows and 15 two-year old calves are slaughtered every year (

Table 7-17), 3 heifers are kept for herd replacement and 1 bull is also kept on pasture. These data can be used to develop an inventory for Irish beef production, which is presented below in Table 7-18.

Table 7-13: Rations for cows and calves per animal for one year.

Animal type	# on farm	Cow milk in pasture		Grazing in pasture		Grass silage and supplement in stable		
		Time (days)	Feed intake	Time (days)	Feed intake (kg grass)	Time (days)	Feed intake (kg grass silage)	(kg supplement)
Calves age 0-1	18	184	-	30	1,519	151	2,491.5	508
Calves age 1-2	18	-	-	214	10,796	151	2,491.5	508
Cows	20	-	-	214	10,796	151	2,491.5	508
Bulls	1	-	-	214	10,796	151	2,491.5	508
Heifers	3	-	-	214	10,796	151	2,491.5	508

Table 7-14: Farming practices for Irish beef.

Farming practices	Unit	Quantity
Target live weight	kg	647
Average daily gain	kg/day	0.87
Lifetime	days	730
Time grazing in pasture	days/year	214
DMI	kg	5,406
DMI/day	kg	7.4

Table 7-15: Lifetime consumption of dietary components per beef animal (Casey & Holden, 2006).

Ingredient	Ration weight (kg as fed)	DM (%)	DM intake (kg)
Fresh Grass	12,355	20.6	2,545.1
Grass silage	4,983	38.4	1,913.5
Supplement	1,016	86.6	879.9
Total consumed	18,354	29 (average)	5,337.9*

**In the original publication, the authors report a different total DM consumed, but this seems to be a type error (as it is identical to the total for the diet listed below).*

Table 7-16: Compound feed composition (Casey & Holden, 2006).

Supplement ingredients	DM (%)	Mass proportion in supplement (%)	Product origin	Comment
Barley	86	29	IE / UK	Assuming 50% UK - 50% IE
Wheat	86	9	IE / UK	Assuming 50% UK - 50% IE
Molasses	75	5	India / Pakistan	Assuming 50% IN - 50% PK
Rapeseed meal	90	15	US / Uzbekistan	Assuming 100% USA
Oats	84	9	US	-
Soya	90	12	Brazil	-
Maize	87	21	US	-
Total	86.6 (average)	100	-	-

Table 7-17: Farm outputs in one year in the Irish beef system

Farm output	Unit	Mass	Comment
Cows for slaughtering	kg	1,995	3 Cows @ 665 kg, replaced by heifers
2-year-old calves for slaughtering	kg	9,705	15 Calves @ 647 kg
Total	kg	11,700	Live weight

Table 7-18: Inventory for Irish beef production

Products			
Beef cattle, at farm/IE Economic	kg	11,700	Total live weight to slaughter per year: 15 x 2-year old calves @647 kg live weight + 3 x cows @665 kg
Resources			
Water, unspecified natural origin/m3	m^3	587.42	Water for drinking
Materials/fuels			
Grass, at beef farm/IE	kg	618,996.5	
Grass silage (beef), at farm/IE	kg	122,137	
Beef cattle compound feed, at processing/IE	kg	32,803	
Energy, from diesel burned in machinery/RER	MJ	68,043.7	
Transport, truck >20t, EURO4, 80%LF, default/GLO	tkm	3,280.3	Transport of feed from feed compound plant to farm
Electricity/heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S	kWh	3,555	
Emissions to air			
Methane, biogenic	kg	2,279.68	CH_4 emissions due to enteric fermentation
Methane, biogenic	kg	642.54	CH_4 emissions due to manure management in stable
Dinitrogen monoxide	kg	4.25	direct N_2O emissions from the stable
Dinitrogen monoxide	kg	5.95	indirect N_2O emissions from the stable
Ammonia	kg	459.69	NH_3 emissions from the stable
Particulates, < 10 um	g	10,200	

7.3 Pig production in the Netherlands

The production of pigs for slaughter is organized in two production stages. In the first stage, sows give birth to piglets. These piglets are raised to about 25 kg, at which stage they are transferred to the second stage of the production system; the pig fattening stage. In this stage, the pigs are fattened to a live weight of about 120 kg. When the pigs have achieved the target weight, they are sent to slaughter. This generally takes about 16-17 weeks. Key parameters for both stages are listed in Table 7-19 and Table 7-20. Table 7-21 provides the ration compositions for the piglets, pigs and sows. Table 7-22 lists the emissions that occur due to enteric fermentation and the production and management of pig manure.

*Table 7-19: Key parameters of the sow-piglet system. Values based on 1 sow*year. a.p.s. = average present sow; a.p.p. = average present pig*

Parameter		Unit	Value	Source	Comment
Piglets per sow to pig fattening		pigs/year	27.6	(CBS, 2011)	-
Average weight of piglets to fattening		Kg	25.1	(CBS, 2011) (Wageningen UR, 2013)	-
Sow replacement		%	41	(Hoste, 2013)	-
Energy use	Electricity	kWh/ a.p.s./ year	150	(Wageningen UR, 2013)	€30, á €0.2/kWh
	Natural gas	m^3/ a.p.s./ year	55.77	(Wageningen UR, 2013)	€29, á €0.52/m^3, is listed as a fuel and assumed to be natural gas.
Water use		m^3/ a.p.s./ year	7.5	(Wageningen UR, 2013)	Since average price of water is 0.79€/m3 per a.p.s.
Sow weight to slaughter	Live weight	kg/sow	230	(Wageningen UR, 2013)	-
	Slaughter weight	kg/sow	167	(Wageningen UR, 2013)	-
Feed input	Sows	kg/ a.p.s.	1,169	(CBS, 2011)	-
	Piglets	kg/ a.p.s.	783	(CBS, 2011)	-
Market price	Sows	€/kg live weight	0.95	(Wageningen UR, 2013)	Sow price based on 1.31 €/kg slaughtered, using ratio between live and slaughter weight from same source.
	Piglets	€/pig	40.80	(Wageningen UR, 2013)	-

Table 7-20: Key parameters of the pig fattening system. a.p.p. = average present pig

Parameter		Unit	Value	Source	Comment
Sow weight to slaughter	Live weight	kg/pig	118	(CBS, 2011)	-
	Slaughter weight	kg/pig	91.1	(Hoste, 2013)	-
Pig throughput		year	3.14	(CBS, 2011)	Based on weight gain per pig and total weight gain per animal place
Energy use	Electricity	kWh/ a.p.p./ year	5	(Wageningen UR, 2013)	1.0 € á €0.2/kWh
	Natural gas	m^3/ a.p.p./ year	1.15	(Wageningen UR, 2013)	0.6 € á €0.52/m^3
Water use		m^3/ a.p.p./ year	3.14	(Wageningen UR, 2013)	This is 0.8 €/pig of water as average price of water is ~0.79 €/m^3 and 3.14 animals per year
Feed input		kg/ a.p.p./ year	763	(CBS, 2011)	Feed conversion rate: 2.6

Table 7-21: Feed rations for pigs based on information from a major feed producer in the Netherlands. Data from 2010.

Feed Ingredient	Unit	Piglets	Sows	Pigs
Wheat grain, market mix, at regional storage/NL	%	26	13	25
Barley grain, market mix, at regional storage/NL	%	36	21	29
Rye grain, market mix, at regional storage/NL	%	0	4	3
Maize, market mix, at regional storage/NL	%	6	4	2
Triticale grain, market mix, at regional storage/NL	%	0	0.5	2
Oat grain, market mix, at regional storage/NL	%	1	0	0
Wheat middlings & feed, at processing/NL	%	2	17	6
Wheat gluten feed, consumption mix, at feed compound plant/NL	%	1	4	1
Maize middlings, consumption mix, at feed compound plant/NL	%	0	2	1
Molasses, market mix, at regional storage/NL	%	1	1	1
Sugar beet pulp dried, at processing/NL	%	1	5	1
Crude palm oil, market mix, at regional storage/NL	%	1	1	1.5
Soybean, consumption mix, at feed compound plant/NL	%	4	0	0
Soybean meal (solvent), market mix, at regional storage/NL	%	13	4.5	8
Soybean hulls, consumption mix, at feed compound plant/NL	%	0	5.5	0.5
Rapeseed meal (solvent), market mix, at regional storage/NL	%	2	4	10
Sunflower seed meal (solvent), market mix, at regional storage/NL	%	2	3	4
Palm kernel expeller, market mix, at regional storage/NL	%	0	8	2.5
Fat from animals, consumption mix, at feed compound plant/NL	%	0	0.5	0.5
Other	%	4	2	2
Total	**%**	**100**	**100**	**100**

Table 7-22: Emissions from manure management and enteric fermentation. a.p.s. = average present sow; a.p.p. = average present pig

Parameter (P)	Sow-piglet system (Kg P/a.p.p./year)	Fattening pig (Kg P/a.p.s./year)	Source	Comment
Manure	5,100	1,100	(CBS, 2011)	
N-content of manure	12.5	30.1	(CBS, 2011)	
CH4 from manure management	4.47	14.5		Based on IPCC calculations, and volatile solid fraction from (Hoek & Schijndel, 2006)
NH_3 emission from manure management	4.90	11.77	(IPCC, 2006b)	Note that emissions reduction systems are in place (see Table 7-23) (Hoek & Schijndel, 2006) that capture a part of produced ammonia. Figures presented here already include emission reduction.
N_2O emissions from manure management	0.16	0.39	(IPCC, 2006a)	Includes both direct and indirect N_2O emissions. Note that emissions reduction systems are in place (see Table 7-23) that capture a part of produced ammonia which is a precursor or of N_2O. Figures presented here already include emission reduction.
CH_4 from enteric fermentation	1.5	1.5	(IPCC, 2006b)	
Particulates PM10	56.1	120.8		Note that emissions reduction systems are in place (see Table 7-23) that capture a part of PM10. Figures presented here already include emission reduction.

In the Netherlands, many stables have emission reduction systems in place either with or without an air washer. These emission reduction systems have a reducing impact on emissions of ammonia and particulate matter. The Dutch CBS publishes data on the fraction of the stables which contain such systems (CBS, 2012). The reduction efficiency has been investigated by Melse et al. (2011) and Giezen & Mooren (2012), see Table 7-23.

Table 7-23: Stable types and reduction efficiency for ammonia and particulate matter for sow-piglet and pig fattening systems.

		Sow-piglet system	Fattening pig	Source
Stable type	Traditional	37%	39%	(CBS, 2012)
	Emission reduction	28%	25%	
	air washer	35%	36%	
Emission reduction NH_3	Traditional	0%	0%	(Melse et al., 2011) (Giezen & Mooren, 2012)
	Emission reduction	30%	30%	
	Air washer	70%	70%	
Emission reduction PM10	Traditional	0%	0%	
	Emission reduction	25%	25%	
	Air washer	50%	50%	

7.3.1 Production of humic acid

HumVi is a product produced by Vitens containing humic and fulvic acids. These substances are filtrated as byproduct to decolor drinking water. HumVi can be added to animal feed as a growth-promoting agent. There are indications that HumVi applied to the soil has beneficial effects on plant and root growth.

The life cycle of the production of HumVi by Vitens starts by filtration of drinking water, which takes place in Oldeholtpade (10%), Sint Jansklooster (12.5%) and Spannenburg (77.5%). All filtrated products are treated at the Spannenburg installation, and therefore the filtrate of Oldeholtpade and Sint Jansklooster are transported to Spannenburg. During the manufacturing process of HumVi, electricity is consumed. Per tonne of HumVi produced, 87.5 kWh is used.

Benefits of using humic and fulvic acids have been reported for plant growth, pig performance and egg production by laying hens, but the effects of adding HumVi as a growth-promoting agent to pigfeed in the production of piglets have been well investigated and documented.

Table 7-7-24: Production of filtrate for HumVi, in Oldeholtpade. Based on manufacturer data.

	Unit	Quantity	Comment
Filtrate from Oldeholtpade for HumVi /NL Economic	kg	1,000	-
Materials/ fuels			
Transport, truck >20t, EURO5, 100%LF, default/GLO Economic	kg	36.0	

Table 7-25: Production of filtrate for HumVi, in Sint Jansklooster. Based on manufacturer data.

	Unit	Quantity	Comment
Filtrate from Sint Jansklooster for HumVi /NL Economic	kg	1,000	-
Materials/ fuels			
Transport, truck >20t, EURO5, 100%LF, default/GLO Economic	kg	41.0	

7.4 Poultry

7.4.1 Laying hens in the Netherlands

The production of consumption eggs consists of two animal production stages. In the first stage the laying hens are bred up to 17 weeks. In the second stage the laying hens are reared, and they start to produce eggs. After a production period (Table 7-26) they are slaughtered. The stables are not filled with animals throughout the whole year, but they remain empty for cleaning in between production rounds.

The breeding of laying hens up to 17 weeks requires energy consumption (electricity and natural gas), water consumption and feed consumption. The system produces laying hens which are ready to start producing consumption eggs.

Table 7-26: Key parameters in the system for breeding of laying hens (<17 weeks). a.p. = animal place. Based on (Wageningen UR, 2013).

Parameter		Unit	Value	Comment
Production period		Days	119	-
Empty period		Days	21	-
Period per round		Days	140	-
Animal places per year		Days	2,607	-
Energy use	Electricity	kWh/ laying hen	0.45	0.09 € per 17 weeks old hen. 0.2 € per kWh electricity (excl. VAT)
	Natural gas	kWh/ laying hen	0.15	-
Water use		dm^3/ laying hen	80	-
Feed input (Laying hens <17 weeks)		Kg/laying hen	5.25	0.3 kg startfeed (0-2.5 weeks)
				1.35 kg breeding feed1 (2.5-9 weeks)
				3.6 kg breeding feed2 (9-17 weeks)
Production (Laying hens <17 weeks)		animals/a.p./year	2.60	

The production of consumption eggs by laying hens older than 17 weeks requires energy consumption (electricity), water consumption and feed consumption. The system produces consumption eggs as well as chickens which are slaughtered for meat. This requires allocation of the environmental impact to the products.

Table 7-27: Key parameters in the system for laying hens (>17 weeks). a.p. = animal place. Based on (Wageningen UR, 2013).

Parameter		Unit	Value	Comment
Rearing period		Days	20	-
Production period		Days	448	-
Empty period		Days	16	-
Period per round		Days	484	-
Animal places per year		Days	0.754	-
Electricity use	For Manure drying	kWh/laying hen	1.35	0.2 € per kWh electricity (excl. VAT)
	Other	kWh/laying hen	0.9	
Water use		dm^3/laying hen	80	-
Feed input (Laying hens > 17 weeks)		Kg/laying hen	49.7	
Production	For slaughter	kg live weight/hen	1.6	1.10kg live weight per a.p./year

	For egg consumption	Egg consumption/hen	383	264.26 egg consumption per a.p./year
Market price	Meat	€/kg live weight	0.176	Average price (2008-12)
	Eggs	€/kg egg	0.854	0.06188 kg/egg

The feed composition of laying hens <17 weeks and >17 weeks is based on Raamsdonk, Kan, Meijer, & Kemme (2007) from RIKILT, see Table 7-28. The energy consumption for the manufacturing of the compound feed is based on the study that was performed for the Dutch Product Board Animal Feed (PDV) by Wageningen University and Blonk Consultants, in which life cycle inventories (LCIs) were developed for crop cultivations used in compound feeds. For one tonne of compound feed, 315 MJ of electricity and 135 MJ of natural gas are required. Feed transport is assumed to be 100 kilometers from the factory to the farm with a truck.

Table 7-28: Feed rations for laying hens.

Feed Ingredient	Unit	Laying hens	
		<17 weeks	>17 weeks
Barley grain, market mix, at regional storage/NL	%	1.51	1.11
Maize, market mix, at regional storage/NL	%	38.6	32.80
Wheat grain, market mix, at regional storage/NL	%	13.26	20.92
Wheat bran, consumption mix, at feed compound plant/NL	%	3.69	4.06
Wheat gluten feed, consumption mix, at feed compound plant/NL	%	0	0.65
Maize gluten feed, dried, consumption mix, at feed compound plant/NL	%	1.61	1.50
Soybean meal (solvent), market mix, at regional storage/NL	%	15.53	13.45
Sunflower seed meal (solvent), market mix, at regional storage/NL	%	2.61	3.22
Cassava root, dried, market mix, at regional storage/NL	%	0.91	1.46
Molasses, market mix, at regional storage/NL	%	0.05	0.11
Crude palm oil, market mix, at regional storage/NL	%	0	0.004
Fat from animals, consumption mix, at feed compound plant/NL	%	3.44	3.41
Peas, dry, market mix, at regional storage/NL	%	1.17	2.15
Soybean, heat treated, consumption mix, at feed compound plant/NL	%	5.62	2.67
Soybeans, market mix, at regional storage/NL	%	0	0.26
Crushed stone 16/32 mm, open pit mining, production mix, at plant, undried*	%	8.82	9.09
Other	%	3.18	3.12
Total	%	100	100

* Crushed stone 16/32, open pit mining, production mix, at plant, undried RER is assumed for limestone

Table 7-29 summarizes manure excretion and emissions. As for pigs, in the Netherlands many stables have emission reduction systems in place either with or without an air washer. These emission reduction systems have a reducing impact on emissions of ammonia and particulate matter. The Dutch CBS publishes data on the fraction of the stables which contain such systems (CBS, 2012). The reduction efficiency has been investigated by Melse et al. (2011) and Giezen & Mooren (2012), see

Table 7-30.

Table 7-29: Excretion of manure and emissions due to manure management for laying hens. a.p. = animal place

Parameter		Unit	Value	Source	Comment
Manure from laying hens	<17 weeks	kg/hen	2.31	(CBS, 2011)	Recalculation from 7.6 kg/a.p./yr for <18 week old hens (through feed consumption)
	>17 weeks	kg/hen	22.43		Recalculation from 18.9 kg/a.p./yr for >18 week old hens (through feed consumption)
N-excretion in manure	<17 weeks	kg N/hen	0.1	(CBS, 2011)	Recalculation from 0.34 kg N/a.p./yr for <18 week old hens (through feed consumption)
	>17 weeks	kg N/hen	0.89		Recalculation from 0.75 kg N/a.p./yr for >18 week old hens (through feed consumption)
CH4 from manure management	<17 weeks	kg CH_4/ a.p./year	0.008	IPCC, 2006a) (Hoek & Schijndel, 2006)	Based on IPCC calculations, and volatile solid fraction from (Hoek & Schijndel, 2006)
	>17 weeks	kg CH_4/ a.p./year	0.023		
NH_3 emission from manure management	<17 weeks	kg NH_3/ a.p./year	0.142	(IPCC, 2006a)	Note that emissions reduction systems are in place that capture a part of produced ammonia. Figures presented here already include emission reduction.
	>17 weeks	kg NH_3 /a.p./year	0.339		
N_2O emissions from manure management	<17 weeks	kg N_2O/ a.p./year	0.002	(IPCC, 2006b)	Includes both direct and indirect N_2O emissions
	>17 weeks	kg N_2O /a.p./year	0.005		Note that emissions reduction systems are in place that capture a part of produced ammonia which is a precursor or of N_2O. Figures presented here already include emission reduction
Emissions of particulate matter	<17 weeks	g < PM10/ a.p./year	24.75	(Ministerie van Infrastructuur en Milieu, 2013)	Note that emissions reduction systems are in place that capture a part of PM10. Figures presented here already include emission reduction.
	>17 weeks	g < PM10 /a.p./year	18.34		

Table 7-30: Stable types and reduction efficiency for ammonia and particulate matter for laying hens.

		Laying hens	
		<17 weeks	>17 weeks
Stable type	Traditional	30%	19%
	Emission reduction	70%	81%
	air washer	0%	0%
Emission reduction NH_3	Traditional	0%	0%
	Emission reduction	30%	30%
	Air washer	70%	70%
Emission reduction PM10	Traditional	0%	0%
	Emission reduction	25%	25%
	Air washer	50%	50%

7.4.2 Broilers in the Netherlands

The production of broilers for chicken meat consists of three animal production stages and a hatchery. In the first stage the broiler parents are bred up to 20 weeks. In the second stage broiler parents are reared and they start to produce eggs for hatching. After a production period they are slaughtered. The eggs are hatched in a hatchery, producing one-day-chicks. In the third system the one-day-chicks are reared in a couple of weeks and slaughtered to produce chicken meat. The stables are not filled with animals throughout the whole year, but they remain empty for cleaning in between production rounds. The breeding of broiler parents up to 20 weeks requires energy consumption (electricity and natural gas), water consumption and feed consumption. The system produces broiler parents of 20 weeks which are ready to start producing eggs for hatching, see Table 7-31.

Table 7-31: Key parameters in the system for breeding of broiler parents (<20 weeks). a.p. = animal place. Based on (Wageningen UR, 2013).

<table>
<tr><th colspan="2">Parameter</th><th>Unit</th><th>Value</th><th>Comment</th></tr>
<tr><td colspan="2">Production period</td><td>Days</td><td>140</td><td>-</td></tr>
<tr><td colspan="2">Empty period</td><td>Days</td><td>21</td><td>-</td></tr>
<tr><td colspan="2">Period per round</td><td>Days</td><td>161</td><td>-</td></tr>
<tr><td colspan="2">Animal places per year</td><td>Days</td><td>2,267</td><td>-</td></tr>
<tr><td rowspan="2">Energy use</td><td>Electricity</td><td>kWh/ broiler parent</td><td>0.7</td><td>-</td></tr>
<tr><td>Natural gas</td><td>kWh/ broiler parent</td><td>0.5</td><td>-</td></tr>
<tr><td colspan="2">Water use</td><td>dm^3/ broiler parent</td><td>20</td><td>-</td></tr>
<tr><td colspan="2" rowspan="3">Feed input
(Broiler parent <20 weeks)</td><td rowspan="3">Kg/ broiler parent</td><td rowspan="3">10</td><td>0.5 kg startfeed (0-1.5 weeks)</td></tr>
<tr><td>1.5 kg breeding feed1 (1.5-5 weeks)</td></tr>
<tr><td>8 kg breeding feed2 (5-20 weeks)</td></tr>
<tr><td colspan="2">Production
(Broiler parent <20 weeks)</td><td>animals/a.p./year</td><td>2.267</td><td>-</td></tr>
</table>

After 20 weeks the broiler parents go to the next system in which they are reared and start producing eggs for hatching. This requires energy consumption (electricity and natural gas), water consumption and feed consumption, see Table 7-32. The system produces eggs for hatching, as well as a small amount of (not fertilized) consumption eggs and the broiler parents are slaughtered for meat at the end of the production round. This requires allocation of the environmental impact to the products.

Table 7-32: Key parameters in the system for the production of eggs for hatching by broiler parents (>20 weeks). Based on (Wageningen UR, 2013).

Parameter		Unit	Value	Comment
Rearing period		Days	14	-
Production period		Days	272	-
Empty period		Days	40	-
Period per round		Days	326	-
Animal places per year		Days	1,120	-
Electricity use	Electricity	kWh/broiler parent	3.9	-
	Natural gas	m^3/broiler parent	0.28	-
Water use		dm^3/ broiler parent	100	-
Feed input (Broiler parent >20 weeks)		Kg/ broiler parent (incl. roosters)	49.2	-
Production	For slaughter	kg / broiler parent	3.67	-
	For egg consumption	Egg / broiler parent	10	-
	Eggs for hatching	Egg / broiler parent	160	-
Market price	Meat	€/kg live weight	0.449	Average price (2008-12)
	Egg consumption	€/kg egg	0.081	
	Eggs for hatching	€/ kg egg	3.056	

The eggs for hatching go to a hatchery where they are hatched, and one-day-chicks are produced. This requires energy consumption; mainly natural gas (Table 7-33).

Table 7-33: Key parameters in the hatchery.

Parameter	Unit	Value	Source	Comment
Input of the hatchery	Eggs/hatching	1,000	(Wageningen UR, 2013)	
Energy use: Natural gas	m^3/1000 eggs for hatching	13.9	(Wageningen UR, 2013) (Vermeij, 2013)	KWIN indicates 12.50€ for electricity, gas and water. Vermeij indicates it is mainly for natural gas.
Production	one-day-chicks	800	(Wageningen UR, 2013)	An 80% hatching rate.

The one-day-chicks are reared in a couple of weeks to become broilers, which are slaughtered for meat production. This requires energy consumption (electricity and natural gas), water consumption and feed consumption (Table 7-34).

Table 7-34: Key parameters in the system for the production of broilers. a.p. = animal place. Based on (Wageningen UR, 2013).

Parameter		Unit	Value	Comment
Production period		Days	41	
Empty period		Days	8	
Period per round		Days	49	
Animal places per year		Days	7,449	
Energy use	Electricity	€/ broiler	0.022	0.20 € per kWh electricity (excl. VAT)
	Natural gas	€/ broiler	0.045	0.52 € per m^3 natural gas (excl. VAT)
Water use		dm^3/ broiler	7	
Feed input (Broilers)		Kg/ broiler	3.78	Feed Conversion Rate: 1.68 kg/kg
Production		Kg meat/broiler	2.25	16.76 kg/a.p./year

The feed composition of broiler parents (<20 weeks & >20 weeks) and broilers (Table 7-35) is based on confidential information from major feed producer in the Netherlands; data from 2010. The energy consumption for the manufacturing of the compound feed is based on the study that was performed for the Dutch Product Board Animal Feed (PDV) by Wageningen University and Blonk Consultants in which life cycle inventories (LCIs) were developed for the cultivation of crops used in compound feeds. For one tonne of compound feed 315 MJ of electricity and 135 MJ of natural gas are required. The assumption was made that the feed is transported over 100 kilometers from the factory to the farm with a truck.

Table 7-35: Feed rations for broiler parents and broilers.

Feed Ingredient	Unit	Broiler parents <20 weeks	Broiler parents >20 weeks	Broilers
Barley grain, market mix, at regional storage/NL	%	3	7	0
Maize, market mix, at regional storage/NL	%	26	17	25
Wheat grain, market mix, at regional storage/NL	%	28.5	34	18
Wheat bran, consumption mix, at feed compound plant/NL	%	7.5	12	0.5
Wheat gluten meal, consumption mix, at feed compound plant/NL	%	1.5	1.25	0
Maize gluten meal, consumption mix, at feed compound plant/NL	%	1.5	0.5	0
Soybean meal (solvent), market mix, at regional storage/NL	%	6.5	3	31
Sunflower seed meal (solvent), market mix, at regional storage/NL	%	6	13	0.5
Rapeseed meal (solvent), market mix, at regional storage/NL	%	5.5	6	11
Oat grain, market mix, at regional storage/NL	%	0.5	1	0.5
Crude palm oil, market mix, at regional storage/NL	%	0.5	0.25	3
Fat from animals, consumption mix, at feed compound plant/NL	%	2.5	1	4
Peas, dry, market mix, at regional storage/NL	%	0.5	0	0
Meat bone meal, consumption mix, at feed compound plant/NL	%	0	0	0.5
Citrus pulp dried, consumption mix, at feed compound plant/NL	%	6.5	0	0
Other	%	3.5	4	6
Total	%	100	100	100

Table 7-36 shows the manure excretion and emissions. In the Netherlands many stables have emission reduction systems in place either with or without an air washer. These emission reduction systems have a reducing impact on emissions of ammonia and particulate matter. The Dutch CBS publishes data on the fraction of the stables which contain such systems (CBS, 2012). The reduction efficiency has been investigated by Melse et al. (2011) and Giezen & Mooren (2012), see Table 7-37.

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Table 7-36: Emissions for broiler parents (<20 weeks and >20 weeks) and broilers. a.p. = animal place

Parameter			Unit	Value	Source	Comment
Manure from	Broiler parent	<20 weeks	kg/ broiler parent	3.960	(CBS, 2011)	Recalculation from 8.2 kg/a.p./yr for <18 week old broiler parents (through feed consumption)
		>20 weeks	kg/ broiler parent	17.690		Recalculation from 10.9 kg/a.p./yr for broilers (through feed consumption)
	Broiler		Kg/broiler	0.530		Recalculation from 20.6 kg/a.p./yr for >18 week old broiler parents (through feed consumption)
N-excretion in manure from	Broiler parent	<20 weeks	kgN / broiler parent	0.160	(CBS, 2011)	Recalculation from 0.33 kg N/a.p./yr for <18 week old broiler parents (through feed consumption)
		>20 weeks	kgN / broiler parent	0.960		Recalculation from 0.55 kg N/a.p./yr for >18 week old broiler parents (through feed consumption)
	Broiler		Kg/broiler	0.060		Recalculation from 0.53 kg N/a.p./yr for broilers (through feed consumption)
CH_4-excretion in manure from	Broiler parent	<20 weeks	kg CH_4/ a.p./year	0.014	(IPCC, 2006b) (Hoek & Schijndel, 2006)	Based on IPCC calculations, and volatile solid fraction from (Hoek & Schijndel, 2006)
		>20 weeks	kg CH_4/ a.p./year	0.031		
	Broiler		kg CH_4/ a.p./year	0.007		
NH_3 emission from manure management	Broiler parent	<20 weeks	kg NH_3/ a.p./year	0.230	(IPCC, 2006b)	Note that emissions reduction systems are in place that capture a part of produced ammonia. Figures presented here already include emission reduction.
		>20 weeks	kg NH_3/ a.p./year	0.607		
	Broiler		kg NH_3/ a.p./year	0.222		
N_2O emissions from manure management	Broiler parent	<20 weeks	kg N_2O/ a.p./year	0.004	(IPCC, 2006b)	Includes both direct and indirect N_2O emissions. Note that emissions reduction systems are in place that captures a part of produced ammonia which is a precursor or of N_2O. Figures presented here already include emission reduction.
		>20 weeks	kg N_2O/ a.p./year	0.01		
	Broiler		kg N_2O/ a.p./year	0.004		
Emissions of particulate matter	Broiler parent	<20 weeks	g < PM10/ a.p./year	0.160	(Ministerie van Infrastructuur en Milieu, 2013)	Note that emissions reduction systems are in place that capture a part of PM10. Figures presented here already include emission reduction.
		>20 weeks	g < PM10/ a.p./year	0.960		
	Broiler		g < PM10/ a.p./year	0.060		

Table 7-37: Stable types and reduction efficiency for ammonia and particulate matter for broiler parents and broilers.

		Broiler parents <20 weeks	Broiler parents >20 weeks	Broilers
Stable type	Traditional	84%	48%	32%
	Emission reduction	16%	52%	61%
	air washer	0%	0%	7%
Emission reduction NH_3	Traditional	0%	0%	0%
	Emission reduction	30%	30%	30%
	Air washer	70%	70%	70%
Emission reduction PM10	Traditional	0%	0%	0%
	Emission reduction	25%	25%	25%
	Air washer	50%	50%	50%

7.5 Slaughterhouse

Animals are slaughtered for meat production in a slaughterhouse. The live weight of the animals is separated into fresh meat, food grade, feed grade and other products (non-food and non-feed) (Luske & Blonk, 2009), according to the mass balance shown in Table 7-38.

Table 7-38: Mass balances of the slaughterhouses for different animal types (Luske & Blonk, 2009).

		Pigs	Chickens	Beef cattle	Dairy cattle
Fresh meat	%	57.00	68.00	45.8	40.4
Food grade	%	10.32	4.48	18.7	20.6
Feed grade	%	27.95	13.76	14.1	15.5
Other	%	4.73	13.76	21.4	23.6
Total		100.00	100.00	100.00	100.00

The energy consumption and water consumption of the Dutch production chain from animal husbandry to retail was mapped including the slaughterhouse for chicken, pigs and beef (www.routekaartvlees.nl, 2012). They are shown in Table 7-39 to Table 7-41.

The water use is not split up transparently in the 'ketenkaarten[10]', so the remainder of the total is assumed to be for general facilities, but some of this can probably be attributed to the slaughterhouse processes directly.

The production of four products from the slaughterhouse (fresh meat, food grade, feed grade and other - non-food & non-feed) requires allocation. This is done based on mass (as is), energy content as well as financial revenue. The results are highly dependent on the choice of allocation. The fresh meat and food grade will have the highest financial revenue, but the feed grade and other non-food and non-feed products represent a significant amount of the mass of all final products. See Table 7-42.

[10] Ketenkaarten is the name used for the maps from (www.routekaartvlees.nl, 2012), made to display the overview of the supply chain.

Table 7-39: Energy and water consumption for chicken meat in the slaughterhouse.

Production line	Action	Electricity (MJ/kg LW)	Natural gas (MJ/kg LW)	Water (l/kg LW)
Slaughter line	Culling	0.001	-	0.025
	Slaughtering process	0.05	-	-
	Conveyor belt	0.01	-	-
	Cleaning the truck	-	-	0.038
	Washing	-	-	1.09
Cooling line	Dry air cooling	0.19	-	-
	Spray cooling	0.155	-	0.05
	Cooling the workspace	0.03	-	-
	Water bath	-	-	0.25
General facilities		0.03	0.13	0.73
Total		0.466	0.13	2.19

Table 7-40: Energy and water consumption for pig meat production in the slaughterhouse.

Production line	Action	Electricity (MJ/kg LW)	Natural gas (MJ/kg LW)	Water (l/kg LW)
Slaughter line	slaughtering process	0.01	-	0.16
	heating tray	-	0.03	-
	oven	-	0.15	-
	washing	-	-	-
Cooling line	dry air cooling	0.14	-	-
	spray cooling	0.11	-	0.16
	cooling the workspace	0.09	-	-
	cutting and deboning	0.001	-	-
General facilities		0.032	0.06	2.15
Total		0.383	0.24	2.47

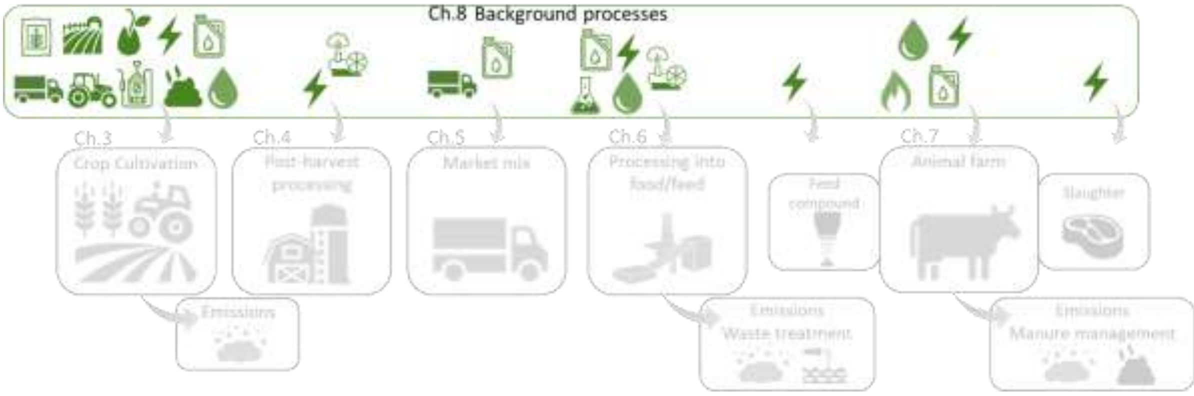
Table 7-41: Energy and water consumption for beef in the slaughterhouse.

Production line	Action	Electricity (MJ/kg LW)	Natural gas (MJ/kg LW)	Water (l/kg LW)
Slaughter line	slaughtering process	0.01	-	0.29
	heating of water	-	0.11	-
	removing the skin	-	-	0.36
Cooling line	dry air cooling	0.27	-	-
	spray cooling	-	-	-
	packing	0.001		-
	cooling the workspace	0.06	-	0.01
	cutting and deboning	0.002	-	0.08
Cleaning line	removing the organs	-	-	0.07
General facilities		0.048	0.04	1.19
Total		0.391	0.15	2.0

Table 7-42: Key parameters required for economic allocation and allocation based on energy content (Blonk et al., 2007), (Kool et al., 2010).

Type of animal	Parameter	Economic allocation (€/kg)	Allocation on energy content (MJ/kg)
Chicken	Fresh meat	1.50	6.14
	Food grade	0.60	7.39
	Feed grade	0.10	6.95
	Other	0.10	7.39
Pig	Fresh meat	1.90	7.00
	Food grade	0.15	14.19
	Feed grade	0.04	9.63
	Other	0.00	7.86
Dairy cattle	Fresh meat	3.00	7.00
	Food grade	0.30	23.68
	Feed grade	0.05	13.15
	Other	0	8.23
Beef cattle	Fresh meat	4.00	7.00
	Food grade	0.30	23.68
	Feed grade	0.05	13.15
	Other	0	8.23

8 Background processes



8.1 Extension of ELCD data

Whenever possible, background data already present in the ELCD database were used. For example, electricity production, production of transport fuels and combustion of natural gas were drawn from the latest version of the ELCD database as implemented in Simapro. However, for 6 waste and wastewater processes[11] the version from the ELCD v3.2 database was used, since the implementation of the latest version of these datasets in Simapro contains serious implementation errors, especially regarding water flows.

8.1.1 Electricity grids outside Europe

As grids from outside Europe are not available in the ELCD database, proxy grids needed to be created, see Table 8-1. Data on production mixes for electricity production were taken from the International Energy Agency (IEA): http://www.iea.org. Electricity production processes by specific fuel types were used from the USLCI and the ELCD to come to country specific electricity production processes, by using the production mix (fuel type) as reported by the IEA. The USLCI and ELCD contain the most contributing fuel types regarding electricity production. For electricity production from biofuels, waste, solar, geothermal and tide the assumption was made that there is no environmental impact. The energy balance was corrected for losses which occur, as reported by the IEA.

[11] Landfill of biodegradable waste EU-27, Landfill of ferro metals EU-27, Landfill of glas/inert waste EU-27, Landfill of municipal solid waste, Waste water - untreated, organic contaminated EU-27, Waste water treatment, domestic waste water according to the Directive 91/271/EE.

Table 8-1: Grids missing from ELCD and production mix used to model the grids based on USLCI and ELCD electricity production processes by specific fuel types.

Countries	Coal & peat (%)	Oil (%)	Gas (%)	Nuclear (%)	Hydro (%)	Wind (%)	Total covered by USLCI and ELCD processes (%)
AR	2	15	51	5	25	0	98
AU	69	2	20	0	7	2	99
BR	2	3	5	3	81	1	94
CA	12	1	10	15	59	2	98
ID	44	23	20	0	7	0	95
IN	68	1	10	3	12	2	97
MY	41	8	45	0	6	0	99
PH	37	5	30	0	14	0	85
PK	0	35	29	6	30	0	100
RU	16	3	49	16	16	0	100
SD	0	25	0	0	75	0	100
US	43	1	24	19	8	3	98

8.2 Transport processes

8.2.1 Road

Fuel consumption for road transport is based on primary activity data of multiple types of vehicles (Table 8-2). These data have been categorized into three types of road transport: small trucks (<10t) medium sized trucks (10-20t) and large trucks (>20t). Small trucks have an average load capacity of 3 tonnes, medium trucks have an average load capacity of 6.2 tonnes and large trucks have an average load capacity of 24 tonnes average.

Small, medium and large trucks have a fuel consumption that is the average within the category of the primary activity data (Table 8-3). Because the fuel consumption has been measured for fully loaded as well as for empty vehicles, the fuel consumption can be adapted to the load factor (share of load capacity used) by assuming a linear relationship between load factor and marginal fuel use.

Table 8-2: Primary activity data for the fuel consumption of road transport.

Type op truck	Classification	Total weight (kg)	Load capacity (tonnes)	Fuel consumption - fully loaded (l/km)	Fuel consumption - empty (l/km)
Atego 818	small truck	7,490	1.79	0.22	0.17
Unknown	small truck	7,100	4.4	0.13	0.10
Atego 1218 autom,	medium truck	11,990	4.99	0.21	0.16
Atego 1218 autom,	medium truck	11,990	4.99	0.21	0.16
Eurocargo 120E18	medium truck	12,000	4.89	0.26	0.19
Eurocargo 120E18	medium truck	12,000	4.89	0.27	0.20
Eurocargo 120E21	medium truck	12,000	4.39	0.27	0.20
Eurocargo 120E21	medium truck	12,000	4.39	0.25	0.19
LF 55,180	medium truck	15,000	4.49	0.26	0.20
LF 55,180	medium truck	15,000	4.49	0.27	0.21
Unknown	medium truck	14,500	9.6	0.24	0.13
Atego trailer 1828	medium truck	18,600	15	0.31	0.24
Unknown	large truck	36,400	25	0.38	0.30
Unknown	large truck	24,000	14	0.35	0.28
Unknown	large truck	40,000	26	0.35	0.25
Unknown	large truck	60,000	40	0.49	0.31

Table 8-3: Categorized primary activity data for vans, small trucks and large trucks.

		Truck <10t (LC 3 tonnes)	Truck 10-20t (LC 6.2 tonnes)	Large truck >20t (LC 24 tonnes)
Fuel use when fully loaded per km	l/km	0.18	0.26	0.39
Fuel use when empty per km	l/km	0.13	0.19	0.28

The emissions due to the combustion of fuels and wear, and tear of roads, and equipment of road transport are based on the reports from Klein et al. (2012b) of www.emisieregistratie.nl, which are based on the methodology by Klein et al. (2012a). The emissions have been monitored in the Netherlands and they are assumed to be applicable for all locations.

Three types of roads are defined: urban area, country roads and highways. In 2010 trucks spent 17.5% of their distance in urban areas, 22.1% of their distance on country roads and 60.4% on highways. These percentages were used for the calculation of emissions when emissions were given per type of road.

Five types of emissions standards are defined: EURO1, EURO2, EURO3, EURO4 and EURO5. These emissions standards correspond with the European emission standards and define the acceptable limits for exhaust emissions of new vehicles sold in EU member states. The emission standards were defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards. Currently, emissions of nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter (PM) are regulated for most vehicle types. The emissions decrease from EURO1 to EURO5.

The naming of the processes is built up of several types of information. First of all, it is a 'Transport, truck,' process. The load capacity is given in tonnes (t), and the emission standard is also given (EURO1-EURO5). The load factor, which is the percentage of the load capacity, which is being occupied, is given in % (%LF). Finally, there are two options related to the return trip. A vehicle can make a complete empty return trip, indicated by 'empty return'. This means that the emissions include a return trip of the same distance but instead of the load factor, which was applied to the first trip, the load factor for the return trip is 0%. In many cases there is no information in the return trip. The vehicle can drive a couple of kilometers to another location to pick up a new load or may have to drive a long distance before loading a new load. Usually the vehicle will not directly be reloaded on the site of the first destination. As a 'default' the assumption has been made that an added 20% of the emissions of the first trip are dedicated to the return trip. Indirectly the assumption is made that a certain amount of the trip to the next location is dedicated to the first trip.

8.2.2 Water

The emissions due to the combustion of fuels of water transport are based on the reports (Klein et al., 2012b) of www.emisieregistratie.nl, which have been calculated based on the methodology by (Klein et al., 2012a).

8.2.2.1 Barge

The fuel consumption of barge ships is based on a publication of CE Delft (den Boer, Brouwer, & van Essen, 2008). There are barge ships which transport bulk (5 types) and barge ships which transport containers (4 types). The types of ships differ in the load capacity and in the fuel consumption (Table 8-4).

Table 8-4: Fuel consumption of 5 types of bulk barges and 4 types of container barges. Based on (den Boer et al., 2008).

		Load capacity (tonnes)	Difference energy use per load % (MJ/km)	Energy use at 0% load (MJ/km)	Energy use at 66% load (MJ/km)
Bulk	Spits	350	0.88	54.92	113
	Kempenaar	550	0.96	114.64	178
	Rhine Herne canal ship	1,350	2.3	260.2	412
	Koppelverband	5,500	3.6	418.4	656
	Four barges convoy set	12,000	4.5	673	970
Container	Neo Kemp	320	1	83	149
	Rhine Herne canal ship	960	2.3	211.2	363
	Rhine container ship	2,000	3.8	319.2	570
	JOWI class container ship	4,700	7.4	551.6	1.040

Most barges run on diesel, and thus the fuel type of barges is set on diesel. The naming of the processes is built up of a couple of types of information. First of all, it is a 'Transport' process. Secondly it is either a 'bulk' barge ship or a 'container' barge ship. The load capacity is given in tonnes (t), and the load factor is given in % (%LF). As in the case of the trucks on the road, there are two options related to the return trip. A barge ship can make a completely empty return trip, indicated by 'empty return', in which emissions include a return trip of the same distance of the first trip but with a load factor of 0%. In many cases there is no information in the return trip. The barge ship can travel several kilometers to another location to pick up a new load or might have to travel a long distance before loading a new load. The barge ship might not directly be reloaded on the site of the first destination. As a ‘default’ the assumption has been made that and added 20% of the emissions of the first trip are dedicated to the return trip. Indirectly the assumption is made that a certain amount of the trip to the next location is dedicated to the first trip.

8.2.2.2 Sea ship

The fuel consumption of the sea ships is based on the model of Hellinga (2002), and it depends on the load capacity of the ship, the load factor and the distance. The fuel type is heavy fuel oil. Load capacity is defined in DWT, which stands for 'dead weight tonnage'. It is the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew, and It measures the weight a ship is carrying or can safely carry.

The model distinguishes four different phases of a trip: a maneuvering phase, a slow cruise phase, a cruising phase and a hoteling phase. The cruising phase is the longest phase of a trip, and before that the ship goes through a maneuvering phase and slow cruise phase. After the cruising phase (before the ship can unload) the ship goes again through a slow cruise and a maneuvering phase. Once in the port the ship has a hoteling phase in which it consumes fuel, but it does not travel any distance. The cruising distance depends on the distance of the trip. The slow cruise distance is assumed to be 20 km (1hour) and the maneuvering distance is assumed to be 4 km (1.1 hour). The hoteling phase is assumed to be 48 hours.

The model calculates the maximum engine capacity based on the DWT. The amount of engine stress and the duration determine the fuel consumption during a phase. The engine stress is set at 80% for the cruise phase, 40% for the slow cruise phase and 20% for the maneuvering phase, but it is also related to the load factor of the ship. When the ship is not fully loaded the engine stress decreases depending on the actual weight and the maximum weight.

Besides the main engines, the sea ship also has auxiliary engines which are operational independently of the traveling speed. These engines power the facilities on the ship. During the cruising and the slow cruising phases, the auxiliary engines power 750 kW; in the maneuvering and the hoteling phases, they power 1250 kW.

The steps which the model uses to calculate the fuel consumption are displayed below (Hellinga, 2002):

Step 1: Calculate maximum engine power (P_{max})

P_{max} (kW) = $(6{,}726 + 0.0985 * DWT) * 0.7457$

Step 2: Calculate empty weight (LDT)

LDT (tonnes) = 2431+0,109*DWT

Step 3: Calculate the maximum ballast weight (BWT)

BWT (tonnes) = IF (DWT < 50,853 ; 0.5314*DWT ; 13,626+0.26345*DWT)

Step 4: Calculate the cruising time

Cruising time (hr) = (distance – slow cruising distance – maneuvering distance) / (14*1.852)

Step 5: Calculate the load

Load (tonnes) = DWT * load factor

Step 6: Calculate the total weight of the ship

Total weight (tonnes)= TW = LDT + IF (load < BWT * 50%/100% ; BWT * 50%/100% ; load)

Step 7: Calculate the maximum total weight of the ship

Maximum weight (tonnes) = DWT + LDT

Step 8: Calculate the actual engine power used per phase

Engine power cruise (kW) = P =$K * TW^{\frac{2}{3}} * V_{cr}^3$

Engine power slow cruise (kW) = $K * TW^{\frac{2}{3}} * V_{scr}^3$

Engine power maneuvering (kW) = $K * TW^{\frac{2}{3}} * V_{man}^3$

Where K is a ship specific constant defined by K=$\frac{0.8 * P_{max}}{(TW_{max})^{\frac{2}{3}} * V_{def}^3}$; where V_{def} is the default cruising speed.

<u>Step 9</u>: Calculate the fuel consumption per phase

Fuel consumption (GJ) per phase i =

$$\left(\frac{14{,}12\left(\frac{P_i}{P_{max}}\right) + 205.717}{1000} * P_i + \frac{14.12 + 205.717}{1000} * P_{aux} \right) * \ cruising\ time_i * \frac{41}{1{,}000}$$

<u>Step 10</u>: Calculate the total fuel consumption by adding the fuel consumption of the cruise, the slow cruise, the maneuvering and the hoteling.

<u>Step 11</u>: Calculate the fuel consumption per tkm

Fuel consumption (MJ/tkm) = $\frac{total\ fuel\ consumption * 1{,}000}{distance * DWT * load\ factor}$

Because the trip distance has a large impact on the fuel consumption and the processes that are based on tkm, the trip distances have been categorized by: ‘short’, ‘middle’ and ‘long’. The short distance can be used for trips shorter than 5,000 km, and its fuel consumption has been calculated using a distance of 2,500 km. The middle distance can be used for trips which are 5,000 – 10,000 km and the fuel consumption has been calculated using a distance of 8,700 km. The long distance can be used for trips longer than 10,000 km, and the fuel consumption based on a distance trip of 20,500 km. The fuel type for sea ships is heavy fuel oil. The fraction of fuel used for cruising, slow cruising, maneuvering, and hoteling is displayed in Table 8-5. (Klein et al., 2012b).

Table 8-5: Fraction of fuel used for traveling phases for short, middle and long distances for sea ships.

Distance	Hoteling (%)	Slow cruise and maneuvering (%)	Cruise (%)
Short	12	34	53
Middle	9	25	66
Long	6	17	77

The naming of the processes is built up of several types of information. First, it is a ‘Transport’ process, and secondly it is sea ship. The load capacity is given in tonnes (DWT), and the load factor, which is the percentage of the load capacity that is being occupied, is given in % (%LF). The trip length can be selected among ‘short’, ‘middle’ or ‘long’. Finally, there are two options related to the return trip. A sea ship can make a complete empty return trip, indicated by ‘empty return’. This means that the emissions include a return trip of the same distance of the first trip but with a load factor set to 0%. In many cases there is no information in the return trip. The sea ship may not be directly reloaded on the site of the first destination, and it may travel few kilometers or long distances to pick up a new load. As a ‘default’, the assumption has been made that an added 20% of the emissions of the first trip are dedicated to the first trip. Indirectly the assumption is made that a certain amount of the trip to the next location is dedicated to the first trip.

8.2.3 Rail

The fuel consumption of freight trains is based on a publication of CE Delft (den Boer, Otten, & van Essen, 2011). There are some trains that run on diesel and others on electricity. Freight trains can transport bulk products as well as containers. The type of terrain also affects the fuel consumption. CE Delft differentiates three types of terrain: flat, hilly and mountainous, and fuel consumption increases as the terrain gets more hilly or mountainous.

Two general assumptions have been made:

- A freight train equals 33 wagons (NW)
- A freight container train never makes a full empty return

The specific energy consumption is calculated based on the gross weight (GWT) of the train. The GWT includes the wagons as well as the freight, but not the locomotive. GWT is calculated as follows:

- GWT for bulk trains (tonnes), loaded = NW × (LF × LCW) + NW × WW
- GWT for bulk trains (tonnes), unloaded = NW × WW
- GWT for container trains (tonnes), loaded = NW × TCW × UC × (CL*LF) + NW × WW

Where the abbreviations are explained as follows:

- NW: Number of wagons
- LF: Load factor
- LCW: Load capacity wagon
- WW: Weight of wagon
- TCW: TEU capacity per wagon
- UC: Utilization TEU capacity
- CL: Maximum load per TEU

Table 8-6 displays the values of the wagon specifications which have been used to calculate the fuel consumption of freight trains transporting bulk or containers.

Table 8-6 Wagon specifications required to calculate the gross weight of freight trains.

Characteristics of a wagon	Unit	Wagon specification for bulk	Wagon specification for containers
LCW	tonnes	42.5	-
WW	tonnes	17.25	16.3
TCW	TEU per wagon	-	2.5
UC	%	-	85
CL	tonnes per TEU	-	10.5

The emissions due to the combustion of fuels of rail transport are based on the reports (Klein et al., 2012b) of www.emisieregistratie.nl,which have been calculated based on the methodology by (Klein et al., 2012a).

The processes are named based on several types of information. First of all, it is a 'Transport' process. Secondly it is a freight train. The freight train either runs on diesel or on electricity, and it either carries bulk or containers. The load factor (the load capacity which is being occupied) is given in % (%LF). Three types of terrain can be selected: 'flat', 'hilly' or 'mountainous'. As explained for the other type of transports, there are two options related to the return trip: (1) a complete empty return trip, indicated by 'empty return', or (2) loaded. In the first case, the load factor for the return trip is set to 0%. In the second case, the train might not directly be reloaded on the site of the first destination, and it may travel short or long distances for new loads. As a 'default' the assumption has been made that and added 20% of the emissions of the first trip are dedicated to the first trip.

Indirectly the assumption is made that a certain amount of the trip to the next location is dedicated to the first trip.

8.2.4 Air

The fuel consumption of airplanes is based on the a publication of the European Environment Agency (European Environment Agency, 2006). Three types of airplanes have been selected: Boeing 747-200F, Boeing 747-400F and Fokker 100. The specifications of these airplanes are given in Table 8-7.

Table 8-7: Specification of the airplanes Boeing 747-200F, Boeing 747-400F and Fokker 100.

Type of airplanes	Weight		Max fuel weight (kg)	Max payload weight (kg)	Max trip length when full (km)	Loading capacity (tonnes)
	When empty (kg)	Max at starting (kg)				
Boeing 747-200F	174,000	377,840	167,500	36,340	12,700	36.34
Boeing 747-400F	178,750	396,890	182,150	35,990	13,450	35.99
Fokker 100	24,500	44,000		11,500	2,800	11.5

Two assumptions have been made:

1. The airplane is always loaded to the maximum loading capacity.
2. The fuel consumption is not dependent on the weight of the load. The airplane itself and the fuel is much heavier and therefore a higher impact on fuel consumption.

The fuel consumption of the airplanes is shown in Table 8-8, Table 8-9 and Table 8-10. The data are used from the European Environment Agency (European Environment Agency, 2006), using the *simple methodology* described by them. The fuel consumption for Landing/Take-off (LTO) cycles does not depend on the distance for this methodology. An LTO cycle consists of taxi-out, take-off, climb-out, approach landing and taxi-in. The climb, cruise and descent depend on the distance of the flight.

The emissions due to the combustion of fuels of air transport are based on the reports (Klein et al., 2012b) from www.emisieregistratie.nl, which have been calculated based on the methodology by (Klein et al., 2012a).

Due to the large impact of trip distance on the fuel consumption and those processes based on tkm, trip distances have been categorized by 'short', 'middle' and 'long', to limit the number of process variants in the database to a practical quantity. The short distance can be used for trips shorter than 5,000 km, and the fuel consumption has been calculated using a distance of 2,700 km. The middle distance can be used for trips which are 5,000 – 10,000 km and the fuel consumption has been calculated using a distance of 8,300 km. The long distance can be used for trips longer than 10,000 km, and the fuel consumption has been calculated using a distance of 15,000 km. The fuel which is used for airplanes is kerosene.

For Boeing airplanes, the maximum payload depends on the maximum starting weight, which is dependent on the highest fuel weight. The amount of fuel that is taken aboard is determined by the trip distance. For the middle distance the loading capacity/ payloads for the Boeing 747-200F and Boeing 747-400F are respectively 69.84 tonnes and 72.42 tonnes; for the short distance, they are respectively 120.09 and 127.07 tonnes. Table 8-7 shows the payload for the long distance.

Processes are named based on a couple of types of information. First of all, it is a 'Transport' process, and secondly it is an airplane. Three types of airplanes can be selected: Boeing 747-200F, Boeing 747-400F and Fokker 100. Finally, the trip length can be selected: 'short', 'middle' or 'long'.

Table 8-8: Fuel consumption of a Boeing 747-200F

Distance (km)	232	463	926	1389	1852	2778	3704	4630	5556	6482	7408	8334	9260	10168
Flight total fuel (kg)	6,565	9,420	14,308	19,196	24,084	34,170	44,419	55,255	66,562	77,909	90,362	103,265	116,703	130,411
LTO	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414
Taxi-out	702	702	702	702	702	702	702	702	702	702	702	702	702	702
Take-off	387	387	387	387	387	387	387	387	387	387	387	387	387	387
Climb-out	996	996	996	996	996	996	996	996	996	996	996	996	996	996
Climb/cruise/descent	3,151	6,006	10,894	15,782	20,671	30,757	41,005	51,841	63,148	74,495	86,948	99,852	113,289	126,997
Approach landing	626	626	626	626	626	626	626	626	626	626	626	626	626	626
Taxi-in	702	702	702	702	702	702	702	702	702	702	702	702	702	702

Table 8-9: Fuel consumption of a Boeing 747-400F

Distance (km)	232	463	926	1389	1852	2778	3704	4630	5556	6482	7408	8334	9260	10168	11112	12038
Flight total fuel (kg)	6,331	9,058	13,404	17,750	22,097	30,921	40,266	49,480	59,577	69,888	80,789	91,986	103,611	115,553	128,170	141,254
LTO	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403	3,403
Taxi-out	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661
Take-off	412	412	412	412	412	412	412	412	412	412	412	412	412	412	412	412
Climb-out	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043	1,043
Climb/cruise/descent	2,929	5,656	10,002	14,349	18,695	27,519	36,865	46,078	56,165	66,486	77,387	88,584	100,209	112,151	124,769	137,852
Approach landing	624	624	624	624	624	624	624	624	624	624	624	624	624	624	624	624
Taxi-in	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661

Table 8-10: Fuel consumption of a Fokker 100

Distance (km)	232	463	926	1389	1852	2778
Flight total fuel (kg)	1,468	2,079	3,212	4,285	5,480	7,796
LTO	744	744	744	744	744	744
Taxi-out	184	184	184	184	184	184
Take-off	72	72	72	72	72	72
Climb-out	185	185	185	185	185	185
Climb/cruise/descent	723	1,334	2,468	3,541	4,735	7,052
Approach landing	120	120	120	120	120	120
Taxi-in	184	184	184	184	184	184

8.3 Auxiliary materials

Note: these processes are used as background processes, and generally data quality is not high (especially for ethanol from ethylene and hexane production). Therefore, if these materials contribute significantly to the overall impact of a system, the data quality needs to be improved.

8.3.1 Bleaching earth

The process for bleaching earth has been based on a paper that explores optimal production parameters for producing bleaching earth (Didi. Makhouki. Azzouz. & Villemin. 2009). The quantities that were considered optimal by the authors have been used to construct an LCI process.

Table 8-11: Inventory for bleaching earth

	Unit	Quantity	Comment
Products			
Bleaching earth	kg	1	-
Materials/fuels			
Sand 0/2, wet and dry quarry, production mix, at plant, undried RER S	kg	1	Based on optimum values from Didi et.al.
Sulfuric acid (98% H_2SO_4)	kg	0.314	-
Process water, ion exchange, production mix, at plant, from groundwater RER S	kg	2.811	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	MJ	3	Assumption, used for drying
Process water, ion exchange, production mix, at plant, from groundwater RER S	kg	10	Washing after treatment assumption
Articulated lorry transport, Euro 0, 1, 2, 3, 4 mix, 40 t total weight, 27 t max payload RER S	tkm	1,000	Transport assumption
Waste and emissions to treatment			
Waste water - untreated, EU-27 S	kg	3.125	-

8.3.2 Sulfur dioxide

Sulfur dioxide is created by burning sulfur. Currently, sulfur is mainly produced as a by-product of fossil fuel refinement, where sulfur is an undesirable component. The burning process is exothermic. It is assumed that the heat generated will be released to atmosphere.

Table 8-12: Inventory for sulfur dioxide production.

	Unit	Quantity	Comment
Products			
Sulfur dioxide	kg	1,000	
Resources			
Oxygen, in air	kg	333.3	From stoichiometry
Materials/fuels			
Sulphur, from crude oil, consumption mix, at refinery, elemental sulphur EU-15 S	kg	666.7	ELCD process. Quantity derived. from stoichiometry
Emissions to air			
Heat, waste	MJ	9,260	From combustion

8.3.3 Sodium Hydroxide and Chlorine

The electrolysis of sodium chloride produces sodium hydroxide but also generates chlorine gas and hydrogen. All products have a commercial value. There are a number of different technologies employed; the amalgam, the diaphragm and membrane cell technology. All these processes depend on electrolysis for the separation of sodium and chloride ions and their reactions to generate the end products, but differ in materials and energy usage, and specific operating conditions. The European Commission created a Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing industry (European Commission. 2001), which describes the technologies in detail. The current production mix was derived from production statistics that were published by the Eurochlor, the European industry body for Chlor-Alkali manufacturers (Eurochlor, 2012; see Table 8-13).

Table 8-13: Production mix (Eurochlor, 2012)

Technology	Production share (%)
Amalgam technology	31.0
Diaphragm technology	13.5
Membrane technology	53.1
Other technologies	2.4

The other technologies (with a combined production share of 2.4%) were modelled and are therefore omitted from the LCI. The inventories for amalgam, diaphragm and membrane technology are listed in Table 8-14, Table 8-15 and Table 8-16, respectively. Note that quantities are listed 'as is', and not the chemical compound.

Table 8-14: LCI for chlorine and sodium hydroxide production using the amalgam technology.

	Unit	Quantity	Comment
Products			
Chlorine, gas, from amalgam technology, at plant	kg	1,000	-
Sodium Hydroxide, from amalgam technology, 50% NaOH, at plant	kg	2,256	-
Hydrogen, gas, from amalgam technology, at plant	kg	28	-
Materials/fuels			
Sodium chloride, production mix, at plant, dissolved RER	kg	1,750	-
Process water, ion exchange, production mix, at plant, from groundwater RER S	kg	1,900	Net water use inputs, some water from the following concentration step is returned to this process, this circular flow is not modelled
Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S	MJ	12,816	-
Mercury, dummy	g	6.75	-
Emissions to air			
Hydrogen	g	550	-
Chlorine	g	8	-
Carbon dioxide	kg	3.1	-
Mercury	g	1.15	-
Emissions to water			
Chlorate	kg	2.07	-
Bromate	g	286	-
Chloride	kg	14.5	-
Hydrocarbons, chlorinated	g	0.595	-
Sulfate	kg	7.65	-
Mercury	g	0.33	-
Waste to treatment			
Landfill of glass/inert waste EU-27	kg	15	brine filtration sludges
Landfill of ferro metals EU-27	g	42	-
Waste water - untreated, EU-27 S	kg	320	-

Table 8-15: LCI for chlorine and sodium hydroxide production using the diaphragm technology.

	Unit	Quantity	Comment
Products			
Chlorine, gas, from diaphragm technology, at plant	kg	1,000	-
Sodium Hydroxide, from diaphragm technology, 12% NaOH, at plant	kg	9,400	Does not mass balance, this diluted stream is concentrated in the next process step, with water condensate returned to this system. This circular flow is not modelled
Hydrogen, gas, from diaphragm technology, at plant	kg	28	-
Materials/fuels			
Sodium chloride, production mix, at plant, dissolved RER	kg	1,750	-
Process water, ion exchange, production mix, at plant, from groundwater RER S	kg	1,900	Net water use inputs, some water from the following concentration step is returned to this process, this circular flow is not modelled
Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S	MJ	10,692	-
Asbestos, dummy	kg	0.2	
Emissions to air			
Hydrogen	g	550	-
Chlorine	g	8	-
Carbon dioxide	kg	3.1	-
Asbestos	mg	0.04	-
Emissions to water			
Chlorate	kg	2.07	-
Bromate	g	286	-
Chloride	kg	14.5	-
Hydrocarbons, chlorinated	g	0.595	-
Sulfate	kg	7.65	-
Asbestos	mg	30	-
Waste to treatment			
Landfill of glass/inert waste EU-27	kg	15	brine filtration sludges
Landfill of ferro metals EU-27	kg	0.145	asbestos to waste
Waste water - untreated, EU-27 S	kg	320	-

Table 8-16: LCI for chlorine and sodium hydroxide production using the membrane technology.

	Unit	Quantity	Comment
Products			
Chlorine, gas, from membrane technology, at plant	kg	1,000	-
Sodium Hydroxide, from membrane technology, 33% NaOH, at plant	kg	3,418	Does not mass balance, this diluted stream is concentrated in the next process step, with water condensate returned to this system. This circular flow is not modelled
Hydrogen, gas, from membrane technology, at plant	kg	28	-
Materials/fuels			
Sodium chloride, production mix, at plant, dissolved RER	kg	1,750	-
Process water, ion exchange, production mix, at plant, from groundwater RER S	kg	1,900	Net water use inputs, some water from the following concentration step is returned to this process, this circular flow is not modelled
Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S	MJ	10,044	-
Emissions to air			
Hydrogen	g	550	-
Chlorine	g	8	-
Carbon dioxide	kg	3.1	-
Emissions to water			
Chlorate	kg	2.07	-
Bromate	g	286	-
Chloride	kg	14.5	-
Hydrocarbons, chlorinated	g	0.595	-
Sulfate	kg	7.5	-
Waste to treatment			
Landfill of glass/inert waste EU-27	kg	15	brine filtration sludges
Landfill of glass/inert waste EU-27	kg	0.6	brine softening sludges
Waste water - untreated, EU-27 S	kg	320	-

8.3.4 Phosphoric Acid

The inventory for phosphoric acid production is based on a publication by Kongshaug (1998) (Table 8-17).

Table 8-17: Inventory for phosphoric acid

	Unit	Quantity	Comment
Products			
Phosphoric acid, merchant grade (75% H_3PO_4) (NPK 0-54-0), at plant /RER	kg	1,000	
Materials/fuels			
Phosphate rock (32% P_2O_5, 50% CaO) (NPK 0-32-0) /RER	kg	1,687	based on P balance
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	1,490	
De-ionised water, reverse osmosis, production mix, at plant, from surface water RER S	kg	420	
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	1.89	
Emission to air			
Water	kg	170	
Waste to treatment			
Landfill of glass/inert waste EU-27	kg	3,865	landfill of gypsum data from Davis and Haglund

8.3.5 Sulfuric Acid

The inventory for sulfuric acid production is based on a publication by Kongshaug (1998). During the production of sulfuric acid, energy is released in the form of steam. It is assumed that this steam can be used elsewhere (on the same production site) and is therefore considered an avoided product (Table 8-18).

Table 8-18: Inventory for sulfuric acid production.

	Unit	Quantity	Comment
Products			
Sulfuric acid (98% H_2SO_4)	kg	1,000	
Avoided products			
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	MJ	3	
Resources			
Oxygen, in air	kg	490	
Materials/fuels			
Sulphur, from crude oil, consumption mix, at refinery, elemental sulphur EU-15 S	kg	326	
De-ionised water, reverse osmosis, production mix, at plant, from surface water RER S	kg	183	

8.3.6 Activated Carbon

The inventory of activated carbon was based on data provided in Bayer, Heuer, Karl, & Finkel (2005). In the activation process, hard coal briquettes are treated with steam and CO_2 at temperatures between 800°C and 1000°C. During the procedure, the product loses around 60% of its original weight, leaving a highly porous material as a result. Other processes that are part of the activated carbon production process are wet grinding, creation of briquettes using a binding agent, oxidation, drying, carbonization, activation (the process described above), crushing, sieving, and packaging. The inventory is listed in Table 8-19.

Table 8-19: Inventory for activated carbon.

	Unit	Quantity	Comment
Output			
Activated Carbon /RER	kg	1	-
Inputs			
Hard coal, from underground and open pit mining, consumption mix, at power plant EU-27 S	kg	3	-
Heat, from resid. heating systems from NG, consumption mix, at consumer, temperature of 55°C EU-27 S	MJ	13.2	Proxy for gas burnt in industrial boiler
Tap water, at user/RER U	kg	12	-
Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S	kWh	1.6	-
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return	tkm	0.4	-
Emissions			
Carbon dioxide	kg	7.33	-
Water	kg	12	-

8.3.7 Hexane

Hexane can be extracted from crude oil during the refining process, through further distillation and the use of molecular sieve technologies. The naphtha fraction from refinery contains hexane and can be further processed to extract the hexane. It is estimated that this additional refining requires 3 MJ energy from steam per kg of hexane (Jungbluth, 2007). As this data is primarily based on estimates, the hexane production process is of low quality and it should not be used when hexane is an important contributor to overall impacts.

8.4 Fertilizers production

Fertilizer production has been modelled based on Kongshaug (1998) and Davis & Haglund (1999). The energy use and block approach have been taken from Kongshaug, while additional data on emissions were sourced from Davis and Haglund. The modelling approach for this dataset differs significantly from EcoInvent. The fertilizer data in this database are presented “as supplied”. So rather than specifying “per kg of N or P_2O_5”, data is presented as a kg of typical fertilizer as supplied to farmers. The NPK values are always listed as well. Figure 8-1 shows the product flow diagram for fertilizer production. As can be seen in the figure, some fertilizers are produced using a combination of intermediate products and/or other fertilizer products. The inventories for fertilizer production are listed in Table 8-20 to Table 8-33. Some other important intermediate products (phosphoric acid and sulfuric acid) are described in previous sections and listed in Table 8-17 and Table 8-18.

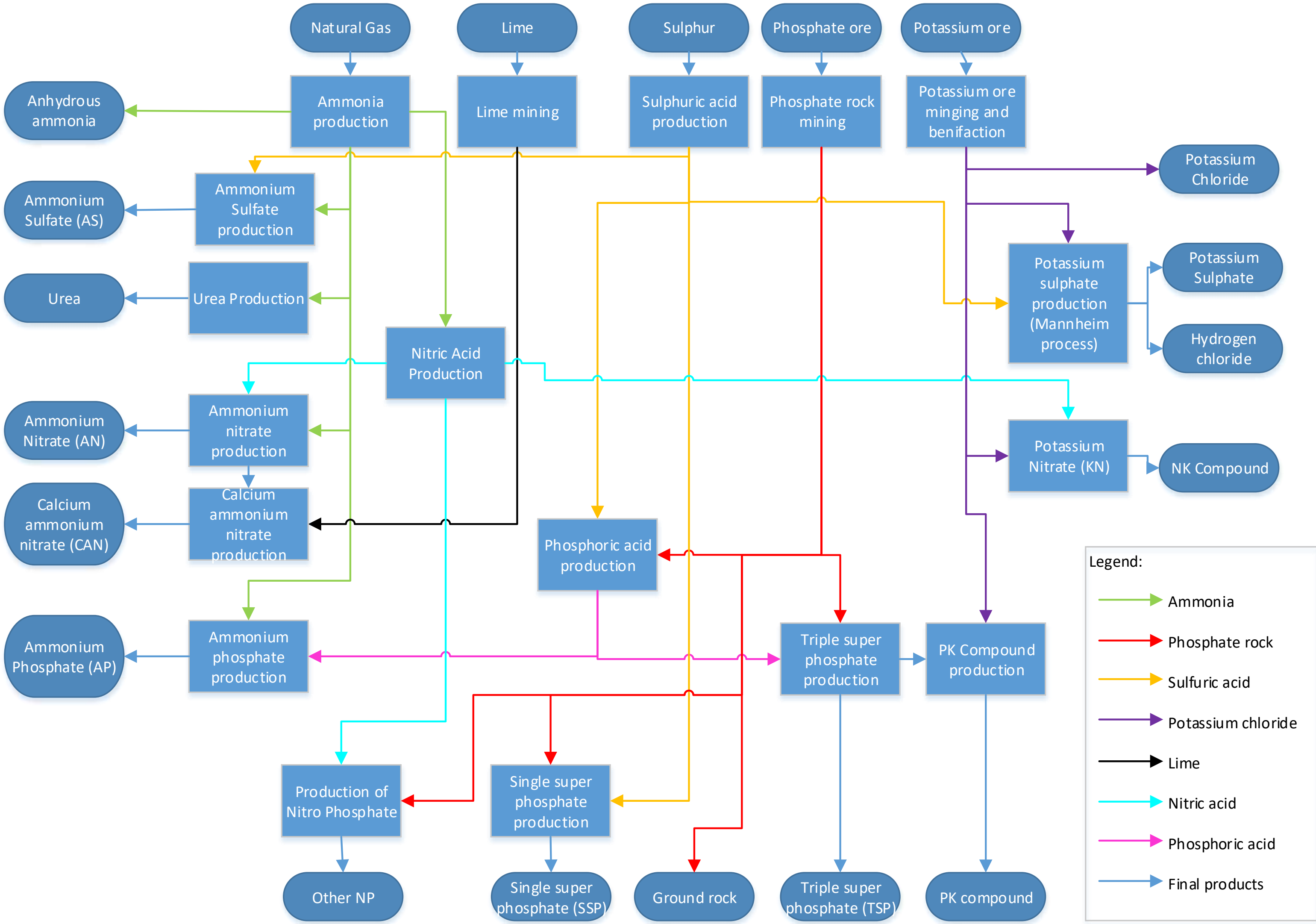


Figure 8-1: Product flow diagram for fertilizer production. The colored lines indicate specific intermediate flows (see legend). Raw materials are listed on the top of the figure, N fertilizers are listed on the left, P fertilizers on the bottom, K fertilizers on the right. Figure based on description in Kongshaug (1998).

Table 8-20: Production of ammonia

	Unit	Quantity	Comment
Product			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER E	kg	1,000	-
Avoided products			
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	2.5	-
Inputs			
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	MJ	5,600	-
Natural gas, from onshore and offshore prod. incl. pipeline and LNG transport, consumption mix, EU-27 S	tonne	0.595	42 MJ/kg
Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S	MJ	200	-
Emissions to air			
Carbon dioxide, fossil	kg	1,218	CO_2 emissions from fuel incineration are included in the process 'Process steam from natural gas'. All CO_2 from feedstock is captured in absorbers and used in Urea making (if applicable). However, ammonia could be also used in other processes where CO_2 cannot be used (in the case it can be vented). Therefore, an input of CO_2 from nature is included in Urea making, to mass balance the CO_2 (no net emissions) and ensure that CO_2 emission is accounted for all other cases.

Table 8-21: Production of calcium ammonium nitrate (CAN)

	Unit	Quantity	Comment
Product			
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at plant /RER	kg	1,000	-
Inputs			
Ammonium nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	756	-
Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S	kg	244	proxy for limestone
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	0.732	transport of limestone to plant

Table 8-22: Production of nitric acid

	Unit	Quantity	Comment
Product			
Nitric acid, in water, as 60% HNO_3 (NPK 13.2-0-0), at plant /RER	kg	1,000	-
Avoided products			
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	0.924	-
Resources from nature			
Oxygen, in air	kg	626	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER E	kg	172	-
De-ionised water, reverse osmosis, production mix, at plant, from groundwater RER S	kg	211.4	-
Emissions to air			
Dinitrogen monoxide	kg	3.96	-
Nitrogen	kg	6.6	-

Table 8-23: Production of ammonium nitrate

	Unit	Quantity	Comment
Product			
Ammonium nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	1,000	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER E	kg	219.07	-
Nitric acid, in water, as 60% HNO_3 (NPK 22-0-0), at plant /RER E	kg	1,312.5	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	1,312.5	-
Emissions to air			
Ammonia	kg	6.57	losses due to conversion inefficiency

Table 8-24: Production of di ammonium phosphate (DAP)

	Unit	Quantity	Comment
Product			
Di ammonium phosphate, as 100% $(NH_3)_2HPO_4$ (NPK 22-57-0), at plant /RER	kg	1,000	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	264	stoichiometric ratios
Phosphoric acid, merchant grade (75% H_3PO_4) (NPK 0-54-0), at plant /RER	kg	1,050	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	0.192	proxy natural gas
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	0.0525	-
Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S	GJ	0.105	-
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	79.2	transport of ammonia to DAP production plant
Emissions to air			
Water	kg	314	-

Table 8-25: Production of Urea

	Unit	Quantity	Comment
Product			
Urea, as 100% $CO(NH_2)_2$ (NPK 46.6-0-0), at plant /RER	kg	1,000	-
Resources			
Carbon dioxide, in air	kg	733	From ammonia production, see note in ammonia inventory.
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	567	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	4.2	-
Emissions to air			
Water	kg	300	-

Table 8-26: Production of triple super phosphate

	Unit	Quantity	Comment
Product			
Triple superphosphate, as 80% $Ca(H_2PO_4)_2$ (NPK 0-48-0), at plant /RER	kg	1,000	Remainder is water
Inputs			
Phosphate rock (32% P_2O_5, 50%CaO) (NPK 0-32-0)	kg	450	30% P_2O_5 from rock
Phosphoric acid, merchant grade (75% H_3PO_4) (NPK 0-54-0), at plant /RER	Kg	622	70% from acid
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	2	energy used in drying, powder production and granulation
Process water, ion exchange, production mix, at plant, from surface water RER S	kg	110	dilution of acid
Transport, sea ship, 60000 DWT, 100% F, short, default/GLO	tkm	1,665	transport of phosphate rock from western Sahara to port in Europe
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	135	transport of phosphate rock from port to phosphoric acid production plant
Emissions to air			
Water	kg	182	vapor released during drying

Table 8-27: Production of single super phosphate

	Unit	Quantity	Comment
Product			
Single superphosphate, as 35% $Ca(H_2PO_4)_2$ (NPK 0-21-0), at plant /RER E	kg	1,000	remainder is $CaSO_4$
Inputs			
Phosphate rock (32% P_2O_5, 50%CaO) (NPK 0-32-0)	kg	656.25	-
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	367.5	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	1.4	-
Transport, sea ship, 60000 DWT, 100%LF, short, default/GLO	tkm	2,428.12	Transport of phosphate rock from western Sahara to port in Europe
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	196.88	

Table 8-28: Production of potassium chloride

	Unit	Quantity	Comment
Product			
Potassium chloride (NPK 0-0-60), at mine /RER	kg	1,000	-
Inputs			
Potassium chloride	kg	1,000	-
Energy, from diesel burned in machinery /RER	GJ	3	-

Table 8-29: Production of potassium sulfate

	Unit	Quantity	Comment
Product			
Potassium sulfate (NPK 0-0-50), Mannheim process, at plant/RER	kg	1,000	92% SOP assume 420 E/t
Hydrochloric acid, 30% HCl, Mannheim process, at plant/RER	kg	1,266.667	assume 140 E/t
Inputs			
Potassium chloride (NPK 0-0-60), at mine /RER	kg	833	-
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	570	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	2.883	-
Electricity mix, AC, consumption mix, at consumer, 1kV – 60kV EU-27 S	GJ	0.217	-
Process water, ion exchange, production mix, at plant, from surface water RER S	kg	887	used for HCl solution
Transport, freight train, diesel, bulk, 100%LF, flat terrain, default/GLO	tkm	1,666	Assumption: all potash is imported from Russia, via rail. 50% electric and 50% diesel
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	1,666	

Table 8-30: Production of NPK compound

	Unit	Quantity	Comment
Product			
NPK compound (NPK 15-15-15), at plant /RER	kg	1,000	-
Inputs			
Potassium chloride (NPK 0-0-60), at mine /RER	kg	250	-
Ammonium Nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	263	-
Di ammonium phosphate, as 100% $(NH_3)_2HPO_4$ (NPK 22-57-0), at plant /RER	kg	263	-
Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S	kg	224	-

Table 8-31: Production of liquid Urea-ammonium nitrate solution

	Unit	Quantity	Comment
Product			
Liquid Urea-ammonium nitrate solution (NPK 30-0-0), at plant/RER	kg	1,000	Solution of Urea and ammonium nitrate in water assume equal ratios by mass
Inputs			
Urea, as 100% $CO(NH_2)_2$ (NPK 46.6-0-0), at plant /RER	kg	366	-
Ammonium Nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	366	-
Process water, ion exchange, production mix, at plant, from surface water RER S	kg	268	-

Table 8-32: Production of PK compound

	Unit	Quantity	Comment
Product			
PK compound (NPK 0-22-22), at plant /RER	kg	1,000	-
Inputs			
Triple superphosphate, as 80% $Ca(H_2PO_4)_2$ (NPK 0-48-0), at plant /RER	kg	458	-
Potassium chloride (NPK 0-0-60), at mine /RER	kg	366.7	-
Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S	kg	175.3	Inert

Table 8-33: Production of ammonium sulfate

	Unit	Quantity	Comment
Product			
Ammonium sulfate, as 100% $(NH_4)_2SO_4$ (NPK 21-0-0), at plant /RER	kg	1,000	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	257.5	-
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	742.5	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	GJ	0.8	-

8.5 Nutramon® (NPK 27-0-0) from OCI nitrogen

The emissions of Nutramon® (NPK 27-0-0) produced by OCI Nitrogen in the Netherlands have been modelled specifically in Agri-footprint based on an earlier carbon footprint study (OCI Nitrogen, 2013). The reason for this is that Nutramon® has a market share of above 50% in the Netherlands and a high share in North-West Europe. The manufacturing of Nutramon® consists of the following steps:

1. Ammonia production from natural gas, which is both the raw material and energy source for this process.
2. Ammonia is converted into nitric acid.
3. Nitric acid is combined with ammonia to produce ammonium nitrate.
4. Calcium carbonate is then added to make calcium ammonium nitrate (CAN).

Most of the emissions from the production of CAN are released during the first two steps. Emissions from the production of Nutramon® are lower than those from traditional production systems because:

- The energy use of ammonia production process is minimized and most of the CO_2 released during the production of ammonia is captured and sold.
- Nitrous oxide (N_2O) has a high global warming potential: each kilogram of N_2O has an effect equivalent to 298 kilograms of CO_2. Almost all the N_2O released during the production of nitric acid at OCI is captured and converted to nitrogen and oxygen gas and so the resulting N_2O emissions are low.
- Nutramon® is produced at the Chemelot site in Geleen, where several chemical companies are located next to each other and residual waste streams are optimally used. The steam from the nitric acid production is passed on to other plants on the Chemelot site, reducing the overall use of fossil energy.

For confidential reasons, the four process steps (ammonia, nitric acid, ammonium nitrate and calcium carbonate addition) are aggregated into a single unit process. The cradle-to-gate calculation from 2013 (OCI Nitrogen, 2013) provided a carbon footprint of 2.06 kg CO_2eq. per kg N from Nutramon® based on 2012 data[12]. This value has been verified by SGS in accordance with the PAS 2050 (BSI, 2011). The input data for the carbon footprint calculations were expanded with data on NO_x and wastewater emissions so SimaPro provides full LCA results. Additionally, the Nutramon® process is modelled as emission per kg Nutramon® and not as kg N in Nutramon® to be more comparable with the other (fertilizer) processes in Agri-footprint. Nutramon® contains 27% nitrogen (N).

[12] The carbon footprint in SimaPro can differ slightly (approximately +/- 3%) compared to the 2013 study because background processes (e.g. natural gas production) are updated.

Table 8-34: Production of Nutramon® (CAN) by OCI Nitrogen

	Unit	Quantity	Comment
Products			
Calcium ammonium nitrate (CAN), Nutramon, (NPK 27-0-0), at OCI Nitrogen plant /N	kg	1,000	-
Avoided products			
Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S	MJ	1,790	Steam delivered to other plants
Materials/fuels			
Combustion of natural gas, consumption mix, at plant, MJ NL S	MJ	10,762	For feedstock and heating
Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S	MJ	711	Steam imported
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S	kWh	73	-
Process steam from heavy fuel oil, heat plant, consumption mix, at plant, MJ NL S	MJ	0.26	Density 0.84 kg/l heavy fuel oil
Dolomite, milled, at mine /RER	kg	223.1	-
Transport, barge ship (bulk), 1350t, 100%LF, empty return	tkm	22.31	Dolomite transport
Heavy fuel oil, from crude oil, consumption mix, at refinery EU-15 S	kg	1.9	Formulation agent
Calcium silicate, blocks and elements, production mix, at plant, density 1400 to 2000 kg/m3 RER S	kg	5.4	-
Drinking water, water purification treatment, production mix, at plant, from groundwater RER S	kg	0.54	-
De-ionised water, reverse osmosis, production mix, at plant, from groundwater RER S	kg	0.43	-
Acrylonitrile-butadiene-styrene granulate (ABS), production mix, at plant RER	kg	0.0107	Solvents
Special high grade zinc, primary production, production mix, at plant GLO S	kg	0.00071	Catalysts
Hydrochloric acid, 30% HCl, Mannheim process, at plant /RER	kg	0.088	-
Sodium Hydroxide 50% NaOH, production mix /RER	kg	0.074	-
Emissions to air			
Dinitrogen monoxide	kg	0.114	
Nitrogen oxides	kg	0.3	
Carbon dioxide	kg	-221.01	Carbon dioxide is captured and diverted to other industrial processes on the industry park.
Waste to treatment			
Waste water - untreated, EU-27 S	kg	210	

8.6 Capital goods

8.6.1 Truck & Tractor production

Truck production is based on an environmental product declaration report of Volvo. In this report the company provides inventory results for the whole life cycle. The resources and materials that are listed are used to determine environmental impact of a truck.

Table 8-35: Material and energy requirements for a 7 ton tractor truck, based on EPD Volvo (Volvo, 2012)

	Unit	Quantity	Comment
Products			
Truck, produced at gate [RER]	p	1	1,000,000 km lifetime
Materials/fuels			
Steel hot rolled coil, blast furnace route, prod. mix, thickness 2-7 mm, width 600-2100 mm RER S	kg	5442	For all steel and iron components
Aluminium sheet, primary prod., prod. mix, aluminium semi-finished sheet product RER S	kg	201	
Lead, primary, consumption mix, at plant DE S	kg	95	Battery
Copper wire, technology mix, consumption mix, at plant, cross section 1 mm² EU-15 S	kg	79	For copper, brass and electronics
Steel hot dip galvanized, including recycling, blast furnace route, production mix, at plant, 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm. GLO S	kg	37	Stainless steel & brake pads
Polyethylene high density granulate (PE-HD), production mix, at plant RER	kg	413	Thermoplastics
Polybutadiene granulate (PB), production mix, at plant RER	kg	465	Tires
Container glass (delivered to the end user of the contained product, reuse rate: 7%), technology mix, production mix at plant RER S	kg	60	Proxy for windows
Polyethylene terephthalate fibres (PET), via dimethyl terephthalate (DMT), prod. mix, EU-27 S	kg	57	Textile
Naphtha, from crude oil, consumption mix, at refinery EU-15 S	kg	62	Proxy for lubricant
Sulfuric acid (98% H2SO4), at plant/RER Mass	kg	36	Battery
Spruce wood, timber, production mix, at saw mill, 40% water content DE S	kg	11	Wood
Ethanol, from ethene, at plant/RER Economic	kg	21	Anti-freeze
Electricity/heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV EU-27 S System - Copied from ELCD	MWh	20	Renewable and non-renewable electricity combined
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	MWh	69	Other renewable and non-renewable energy combined

Next step is to quantify the fraction of the truck that is used for transportation. Using the average load capacity of the truck, load factor, return mode and total distance of the truck during its lifetime, the fraction of truck could be calculated using the following formula.

Amount of truck [p/tkm] = (RF / tkm) / Tdis

Where: RF is return factor (2 for empty return and 1.27 for default return). Tkm amount of cargo on truck during transportation: Average load (depending on class: either 3t, 6.2t or 24t) * LF. Tdis total distance of truck during lifetime: 1,000,000 km.

Since no material compositions could be found for agricultural tractors, the same composition of the Volvo truck will be used to model the production of tractors. Because the functions of trucks and tractors are different from each other, the functional unit needs to be adjusted. As mentioned above, the lifetime of trucks is one million km, but this could not be applied for tractors. Instead, tractors are based on total operational hours during it lifetime. By combining the utilization of tractors per year and the economic lifetime of tractors. Tractors are estimated to have an utilization of 600 hours per year and an economic lifetime of 12 years (Wageningen UR, 2015c). Hereby the production of tractors is evenly divided over 7,200 operational hours during its lifetime.

8.7 Amino acids from Evonik

Evonik is the only company in the world that produces all five essential amino acids for animal feed. A comparative life cycle analysis of the production of amino acids by Evonik Nutrition & Care GmbH, based on ISO 14040:2006 and 14044:2006, was performed and externally reviewed in 2015 (Evonik Nutrition & Care GmbH, 2015). The GaBi model, used for this study, was converted to SimaPro format[13] in 2019 and the LCI's of the different amino acids are included into Agri-footprint as aggregated system process.

The data set covers all relevant process steps / technologies over the supply chain of the represented cradle to gate inventory with a very good overall data quality. The inventory is mainly based on primary industry data and is completed, where necessary, by secondary data.

MetAMINO® is synthesized from petrochemical raw materials using an environmentally friendly patented proprietary process by the feed additives business of Evonik Nutrition & Care GmbH, known as the carbonate process. This proven complex, system results in a high-quality product without the formation of waste salt, while largely avoiding pollution by waste air and water. The product MetAMINO® is produced in Belgium (it is also produced in Germany, US and Singapore but the data is based on the Belgium plant) and contains 99% DL-Methionine (feed grade).

Biolys®, ThreAMINO®, TrypAMINO® and ValAMINO® are produced by a fermentation process. The biotechnological production of these amino acids is predominantly based on sugar either derived from dextrose or saccharose and sucrose as well as corn steep liquor as an additional source for minerals and nutrients. Major parts of the production process are patented by the feed additives business of Evonik Nutrition & Care GmbH.

The product Biolys® is produced in the US and contains 54.6% L-Lysine (feed grade) with a digestibility of 100%, ThreAMINO® is produced in Hungary and contains 98.5% L-Threonine (feed grade) with a digestibility of 100%. TrypAMINO® is produced in Slovakia and contains 98.0% L-Tryptophan (feed grade) with a digestibility of 100%. ValAMINO® is produced in Slovakia and contains 98.0% L-Valine (feed grade) with a digestibility of 100%.

Table 8-36: Naming of amino acid products in Agri-footprint.

Product	Name of process in Agri-footprint
Biolys®	Biolys®, 54.6% L-Lysine, at Evonik plant/US
MetAMINO®	MetAMINO®, 99% DL-Methionine, at Evonik plant/BE
ThreAMINO®	ThreAMINO®, 98.5% L-Threonine, at Evonik plant/HU
TrypAMINO®	TrypAMINO®, 98.0% L-Tryptophan, at Evonik plant/SK
ValAMINO®	ValAMINO®, 98.0% L-Valine, at Evonik plant/SK

Note that the amino acids are only available to the economic allocation library, since the original data is generated using economic allocation.

[13] As the LCI is a result of a conversion from a GaBi model (Kupfer, 2018), no background data of Agri-footprint was used. Also please be aware that SimaPro and GaBi did not align implementation of impact assessment methods in their software. A process with same substance flows and same impact assessment method applied, could therefore result in different environmental impacts on several impact categories.

9 Data quality ratings

9.1 Data quality system and indicators

The DQR for feed materials is consistent with the approach being described in the PEFCR for feed (European Commission, 2018b). The four data quality indicators for feed are:

- Precision
- Time representativeness
- Technological representativeness
- Geographical representativeness

To evaluate the DQR a division needs to be made in type of data and how they are interrelated. Moreover, the data quality shall be applied on a cradle to gate process while taking into account the contribution of data points to the overall environmental impact. Or as stated in the tender specifications:

"The quantification of parameters TeR, GR, TiR, and P shall be based on the results of a contribution analysis carried out on the proposed dataset. The TeR, GR, TiR, and P values for the dataset shall be assigned as weighted average of the corresponding values for the unit processes contributing cumulatively to at least to 80% of the total environmental impact (per impact category) based on characterised and normalised results ".

The DQR evaluation includes activity data and the background data they relate with, being production of goods such as transport and electricity and combustion of fuels or other chemical conversion during processing. This gives the following set of evaluation points.

Table 9-1 DQR criteria used in connection to activity data and background data for production and combustion/conversion

Data type	DQR criterion
Activity data	Precision: P
	Time Representativeness: TiR
	Technology Representativeness: TeR
	Geographical Representativeness: GR
Electricity and energy data from ELCD	Average DQR of the ELCD dataset
Other production data	TiR
	TeR
Combustion or other conversion data	TiR
	TeR

Appendix D gives the overview of the full DQR matrix.

9.2 Data quality of agricultural processes

The approach for agriculture is closely related to how LCI data are generated for cultivation. The DQR of cultivation as a cradle to gate process can be defined as a function of the DQR of background data (production of goods & combustion of fuels) activity data and modelling elementary flows. We only look to the DQR of the activity data in combination with its background data and not to modelling. The agricultural modelling method is defined by EC requirements (Guidance document 6.0) and falls outside the scope of the DQR.

Figure 9-1 shows the list of activity (foreground and background) data to be evaluated.

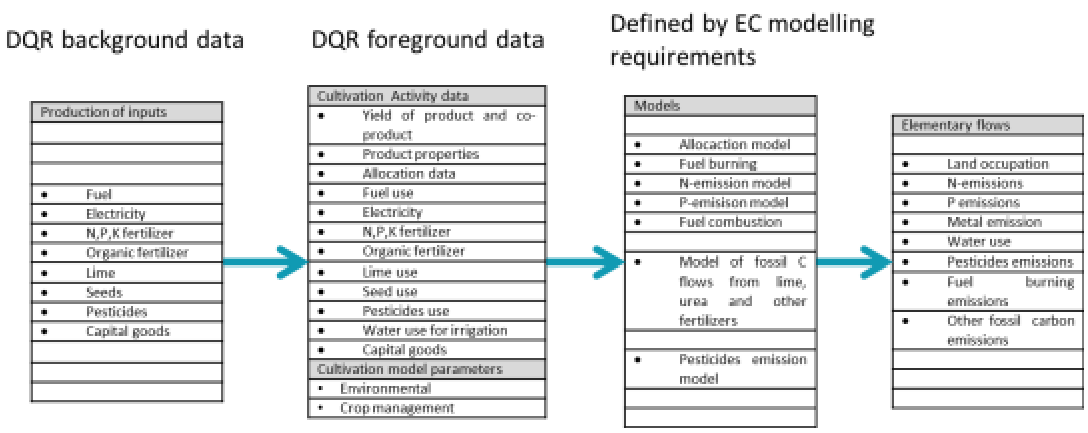


Figure 9-1 Basic scheme to evaluate the DQR of agricultural processes

Activity data for agriculture can be split into:

- Data that determine the quantity of elementary flows per baseline production unit (hectare)
- Data that are used for the scaling of the baseline production unit to the product (yield and allocation)

Therefore, the environmental impact of cultivation can be written as follows

$$ENVIMPcul = \sum Fu.Eu.F.Fo.L.Su.Pu.Wu.CG * \frac{1}{yield} * Allocationfactor$$

Table 9-2 Activity data mentioned in the Formula and how they relate to environmental impact and DQR

Abbreviation	Name	Environmental impact	DQR
Fu	Fuel use [kg/l per ha]	Quantity in combination with production and combustion determines total impact. Production data come from EC T&E dataset. Combustion in agricultural machinery comes from AFP/AGB datasets.	Mathematical average of: 1. Production 2. Use quantity (Ter.Tir. Gr. P) 3. Combustion data (Ter. Tir)
Eu	Electricity use [kwh/ha]	Quantity times production data (country specific)	Mathematical average of: 1. Production 2. Use quantity (Ter.Tir. Gr. P)
F	Fertilizer use [kg product/ha]	Quantity times production data (AFP data sets and ELCD datasets)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
Fo	Organic fertilizer use kg product/ha]	Quantity times production data (AFP data set)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
L	Lime use kg CACO3/ha]	Quantity times production data (ELCD data set)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
Su	Seed use	Quantity times production data (AFP)	Mathematical average of: 3. Production (Ter.Tir) 1. Use quantity (Ter.Tir. Gr. P)
Pu	Pesticides use	Quantity times production data (AFP)	Mathematical average of: 3. Production (Ter.Tir) 1. Use quantity (Ter.Tir. Gr. P)
Wu	Water use	Quantity	1. Use quantity
CG	Capital Goods depreciation	Quantity times production data (AFP)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
Yield	Yield [kg/ha]	Quantity	Quantity
Allocation data	Mass* value Crop rotation	Allocation fractions derived from several data	Quantity

To determine the relevant importance of the activity data (and its related production/combustion data) amongst each other and to yield and allocation a contribution analysis has been conducted. The contribution analysis was performed on four crops which were considered to be representative of the whole database. These four cultivations were: wheat from the United Kingdom; Soybean from Brazil, Maize from France and Rapeseed from Germany. The impact of allocation has been set on default on 2.5% (allocation involves co-product allocation and crop rotation allocation). The impact of yield is set equal to land occupation plus the impact of crop residues and is on average 12.5%. 100% of the impacts and elementary flows are included instead of 80% contribution as being suggested in the PEFCR for feed (European Commission, 2018b).

Table 9-3 Contribution of environmental impacts related to activity data and connected production and combustion

	Wheat UK	Soybean BR	Rapeseed DE	Maize FR	Average contribution 13 ILCD categories equally weighted.
Yield	10.8	18.9	9.9	10.5	**12.5**
Allocation	2.5	2.5	2.5	2.5	**2.5**
Activity data (quantity and composition combined with production and combustion basis for DQR)					
Fuel Use	13.1	12.1	7.4	13.0	**11.4**
Electricity	6.1	3.7	0.0	17.0	**6.7**
NPK	52.0	25.2	57.3	40.2	**43.7**
Organic fertilizer	6.9	14.7	10.0	4.8	**9.1**
Lime use	2.2	3.9	2.9	1.4	**2.6**
Seed use	1.5	1.4	0.1	0.6	**0.9**
Pesticides use	2.7	7.3	4.2	0.4	**3.7**
Water use for irrigation	0.1	0.0	0.0	7.1	**1.8**
Capital goods	2.1	10.3	5.7	2.5	**5.1**
	100.0	100.0	100.0	100.0	**100.0**

The average contribution of activity data of these four crops has been applied for all crops as an average “expected” DQR contribution. Using the procedure above and together with the weighting factors described in Table 9-3 the DQR of crop cultivation was estimated and can be found in Appendix F.

9.3 Data quality of processing agricultural products

For all processing activities the DQR of the process is given, but not weighted. In future versions we try to calculate an overall DQR score of the product using the methodology and weighting factors applied in the PEFCR feed.

Table 9-4: Weighting factors for processed feed products

Activity data	Contribution	
Mass balance	2.5%	
Allocation data	10.0%	
Crop mix	5.0%	
Transport modalities mix	2.5%	
Production of crops	61.9%	Non covered countries in the mix are accounted for with DQR 3 (times share not covered) (see Annex 3 for coverage information)
Transport	3.6%	
Fuel use	3.7%	
Electricity use	7.9%	
Water use	0.1%	
Other raw materials use	1.0%	
Wastewater	1.7%	

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List of tables and figures

List of tables

Table 2-1: Number of process included in Agri-footprint by version. 6
Table 3-1: Prices used for economic allocation of specific crop groups in Agri-footprint 9
Table 3-2: Overview of assumptions in Feedprint cultivation seed production that is applied in Agri-footprint 13
Table 3-3: Overview of modelled emissions, literature source and which aspects are included for the calculations 14
Table 3-4: IPCC Tier 1 emission factors and constants. 19
Table 3-5: Heavy metal content of fertilizers (Mels, Bisschops, & Swart, 2008) 22
Table 3-6: Heavy metal content of manure (Amlinger, Pollak, & Favoino, 2004) 22
Table 3-7: Deposition of heavy metals (Nemecek & Schnetzer, 2012) 24
Table 3-8: Heavy metals in biomass (Delahaye, Fong, Eerdt, Hoek, & Olsthoorn, 2003) 24
Table 3-9 : Heavy metal leaching to groundwater (Nemecek & Schnetzer, 2012) 24
Table 4-1 Electricity and diesel use of nuts used for deriving a nut deshelling default. 27
Table 5-1: How the market mix and coverage is estimated, example of Dutch maize (fictive) market mix 29
Table 5-2: How inventoried products are quantified, production data and ratios used 30
Table 6-1 Simplified list of processed feed and food products, and the related data source that formed the basis of the inventory. 32
Table 6-2 Auxiliary material used in various processes, based on background system processes. 35
Table 6-3: Process in- and outputs of oil refining 40
Table 6-4: Average process in and outputs of oil refining of maize germ oil, rice bran oil, coconut oil, linseed oil. 40
Table 6-5: Key parameters required for mass, energy and economic allocation. 41
Table 6-6: Estimated key parameters required for mass, energy and economic allocation for other refined oils and soap stock. 41
Table 6-7: Key parameters for mass, energy and economic allocation. 42
Table 6-8: Gas emissions from combustion of 280 kg of bagasse ‘as is’ (wet-mass). 46
Table 7-1: Primary data sources for dairy farm parameters 47
Table 7-2: Herd size at the average Dutch dairy farm in 2011. 48
Table 7-3: Energy consumption at the average Dutch dairy farm in 2011. 48
Table 7-4: Dry matter intake (DMI) of the animals on the average Dutch dairy farm in kg dry matter (DM) per animal per year. 48
Table 7-5: LCI for the cultivation of maize silage on the Dutch dairy farm. 49
Table 7-6: LCI for the cultivation of fresh grass on the Dutch dairy farm. 49
Table 7-7: LCI for the production of grass silage from fresh grass. 49
Table 7-8: LCI for the manufacturing of compound feed for dairy (base feed and protein-rich). The average dairy feed contains many ingredients. A dairy feed has been made with the top ingredients. The extra impact is estimated by not making a reference flow of 100 kg (because not 100% of the ingredients are accounted for) but for 93 kg. 50

Table 7-9: LCI for the mix of wet by-products fed to dairy cows. Dry matter: Handboek Melkveehouderij 2012, chapter 6, table 6.24 50
Table 7-10: Water needs for dairy cattle (Wageningen UR, 2012a) 51
Table 7-11: Yearly excretion of nitrogen, phosphorous, manure, and methane emission due to enteric fermentation for each animal type on the average Dutch dairy farm. 51
Table 7-12: Parameters for physical allocation on the dairy farm. 52
Table 7-13: Rations for cows and calves per animal for one year. 53
Table 7-14: Farming practices for Irish beef. 53
Table 7-15: Lifetime consumption of dietary components per beef animal (Casey & Holden, 2006).. 53
Table 7-16: Compound feed composition (Casey & Holden, 2006). 53
Table 7-17: Farm outputs in one year in the Irish beef system 55
Table 7-18: Inventory for Irish beef production 55
Table 7-19: Key parameters of the sow-piglet system. Values based on 1 sow*year. a.p.s. = average present sow; a.p.p. = average present pig 56
Table 7-20: Key parameters of the pig fattening system. a.p.p. = average present pig 57
Table 7-21: Feed rations for pigs based on information from a major feed producer in the Netherlands. Data from 2010. 57
Table 7-22: Emissions from manure management and enteric fermentation. a.p.s. = average present sow; a.p.p. = average present pig 58
Table 7-23: Stable types and reduction efficiency for ammonia and particulate matter for sow-piglet and pig fattening systems. 59
Table 7-7-24: Production of filtrate for HumVi, in Oldeholtpade. Based on manufacturer data. 59
Table 7-25: Production of filtrate for HumVi, in Sint Jansklooster. Based on manufacturer data. 59
Table 7-26: Key parameters in the system for breeding of laying hens (<17 weeks). a.p. = animal place. Based on (Wageningen UR, 2013). 60
Table 7-27: Key parameters in the system for laying hens (>17 weeks). a.p. = animal place. Based on (Wageningen UR, 2013). 60
Table 7-28: Feed rations for laying hens. 61
Table 7-29: Excretion of manure and emissions due to manure management for laying hens. a.p. = animal place 62
Table 7-30: Stable types and reduction efficiency for ammonia and particulate matter for laying hens. 62
Table 7-31: Key parameters in the system for breeding of broiler parents (<20 weeks). a.p. = animal place. Based on (Wageningen UR, 2013). 63
Table 7-32: Key parameters in the system for the production of eggs for hatching by broiler parents (>20 weeks). Based on (Wageningen UR, 2013). 64
Table 7-33: Key parameters in the hatchery. 64
Table 7-34: Key parameters in the system for the production of broilers. a.p. = animal place. Based on (Wageningen UR, 2013). 64
Table 7-35: Feed rations for broiler parents and broilers. 65
Table 7-36: Emissions for broiler parents (<20 weeks and >20 weeks) and broilers. a.p. = animal place 66
Table 7-37: Stable types and reduction efficiency for ammonia and particulate matter for broiler parents and broilers. 67

Table 7-38: Mass balances of the slaughterhouses for different animal types (Luske & Blonk, 2009). 67
Table 7-39: Energy and water consumption for chicken meat in the slaughterhouse. 68
Table 7-40: Energy and water consumption for pig meat production in the slaughterhouse. 68
Table 7-41: Energy and water consumption for beef in the slaughterhouse. 68
Table 7-42: Key parameters required for economic allocation and allocation based on energy content (Blonk et al., 2007), (Kool et al., 2010). 69
Table 8-1: Grids missing from ELCD and production mix used to model the grids based on USLCI and ELCD electricity production processes by specific fuel types. 71
Table 8-2: Primary activity data for the fuel consumption of road transport. 72
Table 8-3: Categorized primary activity data for vans, small trucks and large trucks. 72
Table 8-4: Fuel consumption of 5 types of bulk barges and 4 types of container barges. Based on (den Boer et al., 2008). 73
Table 8-5: Fraction of fuel used for traveling phases for short, middle and long distances for sea ships. 75
Table 8-6 Wagon specifications required to calculate the gross weight of freight trains. 76
Table 8-7: Specification of the airplanes Boeing 747-200F, Boeing 747-400F and Fokker 100. 77
Table 8-8: Fuel consumption of a Boeing 747-200F 78
Table 8-9: Fuel consumption of a Boeing 747-400F 78
Table 8-10: Fuel consumption of a Fokker 100 79
Table 8-11: Inventory for bleaching earth 80
Table 8-12: Inventory for sulfur dioxide production. 80
Table 8-13: Production mix (Eurochlor, 2012) 81
Table 8-14: LCI for chlorine and sodium hydroxide production using the amalgam technology. 82
Table 8-15: LCI for chlorine and sodium hydroxide production using the diaphragm technology. 83
Table 8-16: LCI for chlorine and sodium hydroxide production using the membrane technology. 84
Table 8-17: Inventory for phosphoric acid 85
Table 8-18: Inventory for sulfuric acid production. 85
Table 8-19: Inventory for activated carbon. 86
Table 8-20: Production of ammonia 88
Table 8-21: Production of calcium ammonium nitrate (CAN) 88
Table 8-22: Production of nitric acid 89
Table 8-23: Production of ammonium nitrate 89
Table 8-24: Production of di ammonium phosphate (DAP) 90
Table 8-25: Production of Urea 90
Table 8-26: Production of triple super phosphate 91
Table 8-27: Production of single super phosphate 91
Table 8-28: Production of potassium chloride 92
Table 8-29: Production of potassium sulfate 92
Table 8-30: Production of NPK compound 92
Table 8-31: Production of liquid Urea-ammonium nitrate solution 92
Table 8-32: Production of PK compound 93
Table 8-33: Production of ammonium sulfate 93
Table 8-34: Production of Nutramon® (CAN) by OCI Nitrogen 95

Table 8-35: Material and energy requirements for a 7 ton tractor truck, based on EPD Volvo (Volvo, 2012).. 96
Table 8-36: Naming of amino acid products in Agri-footprint. 98
Table 9-1 DQR criteria used in connection to activity data and background data for production and combustion/conversion 99
Table 9-2 Activity data mentioned in the Formula and how they relate to environmental impact and DQR.. 100
Table 9-3 Contribution of environmental impacts related to activity data and connected production and combustion.. 101
Table 9-4: Weighting factors for processed feed products.. 102
Table 0-1 Share of active ingredients per pesticide super group [%]. I Herbicide basic cocktail, II Insecticide basic cocktail, III Fungicide basic cocktail.. 120
Table 0-2 List of "Not Approved" substances in EU. Status under Status under Reg. (EC) No 1107/2009. 121
Table 0-3 Example of pesticide inventory; Soy bean cultivation in Argentina, based on Agri-footprint 5.0 pesticide modelling. 121

Table A-1: Cut-off values for N, P2O5 and K2O applications. 116
Table C-1:List of crops and countries combinations in Agri-footprint 123
Table D-1: DQR legend table. 125
Table D-2: Rating of cultivation activity data in Agri-Footprint 5.0 127
Table E-1:Rating of cultivation activity data from AFP for countries (except France) 129
Table F-1: Baseline (worst case) rating of cultivation data in Agri-footprint.................................... 130

List of figures

Figure 1-1 General agri-food supply chain representative of most Agri-footprint life-cycle stages. Indicated are also the chapter of reference for the data description. 5
Figure 3-1: Cultivation LCI example of Wheat cultivation in Germany as shown in SimaPro................ 8
Figure 3-2: Nitrous oxide emission (direct and indirect) from due to different N inputs (IPCC, 2006c). 15
Figure 3-3: Emission factors for ammonia emissions from fertilizers (g NH_3/kg N applied) (European Environment Agency, 2016) 20
Figure 3-4: Range of heavy metal contents in different animal manures in the EU. CS = Cattle slurry, CM =Cattle manure , PiS =Pig slurry , PiM =Pig manure , PoD = Poulty dung, S&G =Sheep and goat manure , BWC = Biowaste compost (Amlinger et al., 2004) 23
Figure 5-1: Graphic illustration of how market mixes are calculated in Agri-Footprint 28
Figure 5-2: Generic transport model from a central hub in land of cultivation to the market location within a specific country. 31
Figure 6-1 Wet milling of maize (van Zeist et al., 2012f)... 36
Figure 6-2: Diagram describing the process of production of rice without husks and rice husks from a rice dry milling process.. 37
Figure 6-3: Diagram describing the process of production of white rice, rice husks, rice bran and rice brokens from a rice dry milling process in China. 38

Figure 6-4 Lupin protein-concentrate production process (Veghel van, 2017). 42
Figure 6-5 Soy protein-concentrate production process (Veghel van, 2017). 43
Figure 6-6 Pea protein-concentrate production process (Veghel van, 2017). 43
Figure 6-7 Soy protein-isolate production process (Veghel van, 2017). 44
Figure 6-8 Lupin protein-isolate production process (Veghel van, 2017). 44
Figure 6-9 Pea protein-isolate production process (Veghel van, 2017). 44
Figure 8-1: Product flow diagram for fertilizer production. The colored lines indicate specific intermediate flows (see legend). Raw materials are listed on the top of the figure, N fertilizers are listed on the left, P fertilizers on the bottom, K fertilizers on the right. Figure based on description in Kongshaug (1998). 87
Figure 9-1 Basic scheme to evaluate the DQR of agricultural processes 100
Figure A-1 Top-down model conceptualization. The number indicated inside the boxes will be used throughout the text to help the reader identifying the specific step in the model. 115

Appendices

Appendix A. NPK model

To estimate the Nitrogen, Phosphorus and Potassium (NPK) application for specific country-crop combinations, a top-down model has been designed (Figure A-1). Nitrogen application are here expressed under the form of N, phosphorus as P2O5 and potassium as K2O.

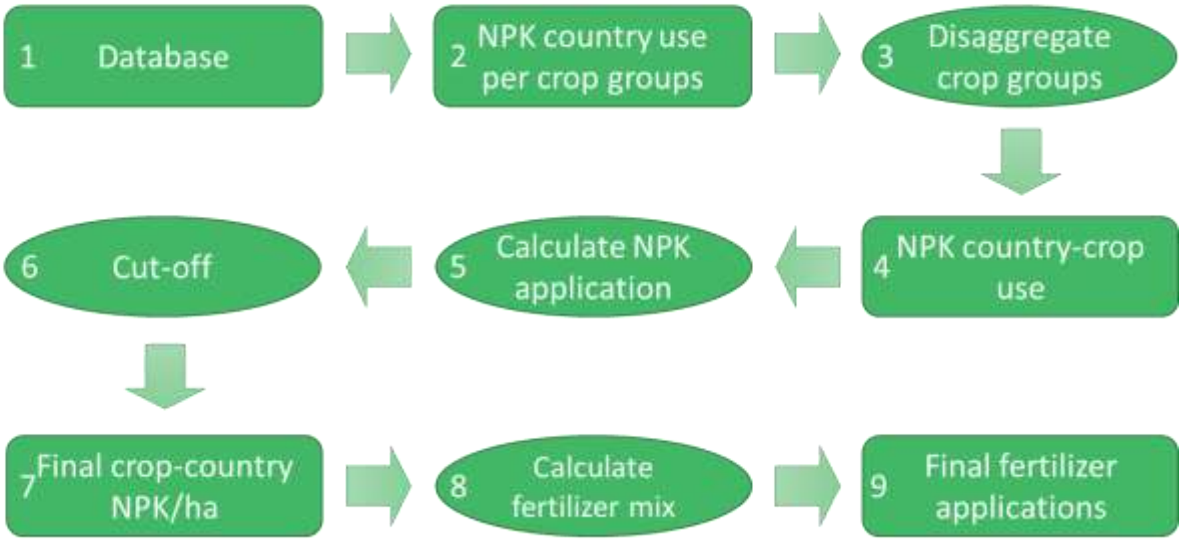


Figure A-1 Top-down model conceptualization. The number indicated inside the boxes will be used throughout the text to help the reader identifying the specific step in the model.

The model database (1) is based on national statistics available on NPK land application per country (IFA, 2019a), production and harvested area of country-crop combinations (FAO, 2018a) and estimates of fertilizer use by crop category per country (Heffer et al., 2017). In particular, the last cited study allowed to derive from the overall NPK use in a specific country (Heffer, Gruère, & Roberts (2017), average 2012-2016), how much was used for cultivation of crops (4) (wheat, rice, maize, soybean and oil palm) and crop groups (2) (other cereal, other oil seed, fibre crops, sugar crops, roots & tuber, fruits and vegetables). For the fertilizer use by crop group in a specific country a model was developed (3). For each country/crop group combination three (for N, P2O5 and K2O) parameter R (kg/kg) requirement are calculated:

$$R_{NPK} = \frac{kg_{NPK}}{\sum(kg_{prod,c} * DM_c)}$$

where kg_{NPK} is the kg of N, P_2O_5 or K_2O used for a certain country/crop group combination, $kg_{prod.c}$ is the production in kg of the specific crop c and DM_c is the dry matter content (kg/kg) of the specific crop c.

The dry matter content was retrieved from USDA (2019), RIVM (2016) and in the few cases from literature.

The parameter R represent how much NPK is required to have 1 kg of solids as output. It is then multiplied by the dry matter yield (FAOSTAT data * DM content) to calculate the NPK application per hectare (5). For the one-crop groups was possible derive the NPK application directly (5), by dividing the fertilizer use by crop in a specific country by the production area reported by FAOstat for the specific country-crop combination (average 2013-2017).

Other options were investigated, such as express the NPK use per kg as is. The chosen option avoids allocating NPK to a crop just because contain high water contents, this is relevant for oilseed (specifically coconuts and olives) and for fruit and vegetables, that show a large variability in water content. Another discarded option was calculating NPK use per kg of specific nutrient (NPK). Calculating the NPK application based on the NPK extraction from field is a common agricultural practice. The option of further considering NPK content was discarded due to the high uncertainty and variability in NPK content, even between the same crop in different countries or cultivation practices.

Since the estimation are based on global statistics from two different source, we considered the possibility of inconsistent or unrealistic estimates. This is more relevant for low produced crops (inconsistency between IFA percentages per crop and FAO harvested areas), rare for largely produced crop. Cut off criteria were therefore selected based on previous literature search performed by Blonk Consultants (6) (

Table A-1: Cut-off values for N, P2O5 and K2O applications.). When an estimation resulted higher than the selected cut-off the values was considered unreliable and not used for the LCI.

Table A-1: Cut-off values for N, P2O5 and K2O applications.

Cultivation type	kg N/ha	kg P2O5/ha	kg K2O/ha
Arable/Paddy	550	500	700
Orchard	750	250	1500

The main limitation of the model is that Europe is reported as an aggregated country, therefore it was not possible derive NPK application for the various European country. The European NPK application in AFP5.0 has not been modified compared with older version of the database; they are based on literature (Pallière, 2011; Rosas, 2011).Including EU in the model has high priority for the next Agri-footprint updates.

Other countries excluded from the scope of the model are the one included by Heffer et al. (2017) in Rest of the World (ROW). Pulses, tree nuts, coffee, cocoa and tea are included in the group “residual” in the cited report, together with other non-agricultural uses. It was therefore not possible to disaggregate these fertilizer uses. Even though grass is a disaggregated NPK use in the cited report, FAO surface data on how much grass surface is naturally growing, and how much is cultivated are incomplete. Pulses, tree nuts, coffee, cocoa, tea and grass are therefore out of the scope of the model. NPK application for out of scope country-crop combinations are based on literature (Pallière, 2011; Rosas, 2011).

Another limitation of the model is related to legumes. Three crops included in the vegetable crop group are indeed legumes (green peas and green beans). But since the N application is based on solids extraction from field, it does not account for the fact that nitrogen is fixated by the plants. This usually results in lower N application on field. The option of including a N fixation rate of the specific legume was investigated but discarded due to low data reliability.

To match these total N, P and K application rates (7), to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.), data on regional fertilizer consumption rates from IFA (2019) were used (8).

Some fertilizers supply multiple nutrient types (for example ammonium phosphate application supplies both N and P to agricultural soil). In IFA statistics (IFA, 2019a), the share of ammonium phosphate is given as part of total N and also as part of total P supplied in a region. To avoid double counting, this dual function was taken into account.

Therefore, the following calculation approach was taken:

1. A fertilizer type is considered in isolation (e.g. only Potassium supplying fertilizers, or only Nitrogen). The relative shares of the specific fertilizers were calculated for a crop (e.g. if a crop A in Belgium requires 10 kg K/ha, 35% is supplied from NPK, 52% from Potassium Chloride and 11% from Potassium Sulfate). However, some fertilizers supply nutrients of different types (e.g. both N and P or N, P and K). The amounts of other nutrients supplied are subtracted from the total nutrient requirements.

2. Next, the share of the second fertilizer type is calculated, taking into account the amount of nutrient supplied by multi-nutrient fertilizers from the previous step. Again, other nutrients supplied are subtracted from the requirements for the last fertilizer type.
3. For the remaining nutrient, the single nutrient supplying fertilizers are used (as NPK and ammonium phosphate etc. are already considered during previous calculation steps).

In this approach, there are 6 different calculation routes (K then P then N, K then N then P and so forth). For most cases, these routes all yield similar answers. However, in some extreme cases (e.g. no K supplied, and high amount of N supplied), there is a risk of calculation negative application rates when the calculation starts with the nutrient with the highest quantity supplied (i.e. for most crops this would be N). For example, if an overall crop requirement is 100 kg N, 10 kg P and 0 kg K and the calculation is started with calculation the specific shares of N fertilizers first, the calculation results in a certain amount of NPK fertilizer being applied. However, as K requirement is zero, this cannot be true. However, if one starts with the smallest nutrient type being applied (in this case 0 kg K), no NPK will be applied, and the other nutrient requirements can be supplied by pure N and P or NP fertilizers.

For consistency, the approach used for Agri-footprint is therefore to determine the order of N, P and K from smallest to largest for each specific crop/country combination and use that order for the calculation (9). E.g. for a crop requiring N:60 kg, P:20 kg, K: 30 kg, the calculation starts with calculating the shares of specific fertilizers for P then K and finally N.

Appendix B. Pesticide model

Scope / limitations of the inventory

The scope / limitations of this inventory are:

- The inventory provides is on a crop-country level (e.g. soybean cultivation in Brazil).
- The focus is on pesticides use in crop cultivation so seed treatment, pesticides used for crop storage / transport and soil disinfection were not included.
- The location, technique of application and timing of application is not taken into account. These factors can be highly significant for emissions to various environmental compartments and are hence important for ecotoxicity impact scores. However, due to the complexity (and uncertainties) involved in modelling these impacts, average conditions are taken into account in standard impact assessment methods such as ReCiPe.
- Only insecticide, herbicide and fungicide applications were considered. Other phytosanitary measures, as rodenticides or mineral oil applications are outside the scope of this inventory.
- Basic active ingredient mixes were defined for herbicide, insecticide and fungicide (H/I/F) respectively based on top 80% active ingredient use per H/I/F group in Netherlands, France and United States of America.
- The same active ingredient mix of each pesticide type is used for all crops and countries considering only differences for the EU region, where certain active ingredients are not allowed.

Inventory development process

Agri-footprint 5 modelling of pesticide use per crop/country (kg a.i/ ha) follows the steps described below.

Step 1: FAOstat country use data per supergroup

Herbicides, insecticides and fungicides are the three large pesticide supergroups covered in Agri-footprint 5. In section ? we refer generally as pesticide supergroup to these three pesticide categories.

The first step on the inventory development was to obtain country specific data for total pesticide supergroup active ingredient use per year. FAOstat compiles national statistics on total herbicide, total insecticide and total fungicide use in tonnes of active ingredient per year (FAO, 2019b). FAO pesticide use statistics were implemented considering a five-year average from 2012 to 2016.

Step 2: Pesticide application per supergroup per crop

FAO statistics do not provide details on the amount of active ingredient of each pesticide supergroup used per hectare of cultivated crop. This was defined using a two-step approach.

First, the total active ingredient used per supergroup (tonne/year) was distributed per crop based on the share of the annual harvested area of each crop to the total national harvested area. This was done using FAOstat data on ha crop/year considering a five-year average from 2012 to 2016.

This first step results on the same use of active ingredient of supergroup per hectare for all crops in a given country. This is logically not the case. Different crops have different pesticide use needs, some being high, as for example soft fruits, or others low as cereals. We had to define a way to reflect this "pesticide use intensity" for each crop, needing to include a weighing factor to the distribution of the national pesticide use among crops, considering more than the harvested area per crop.

The best way to estimate this weighing factors per crop was to look at the limited number of available national statistics on active ingredient application per crop and observe the real active ingredient annual dosage (kg a.i./ha) for different cultivation systems.

We looked at national statistics of pesticide application from France (AGRESTE, 2018), The Netherlands (CBS, 2018) and the United States (USDA-NASS, 2019). These three countries were chosen because their data was readily available, had relatively large crop coverage and detail on specific active ingredient use per crop (at a.i. per supergroup and a.i. per active chemical substance level). Other available country statistics did not meet one or several of these criteria, so were not able to be used for our model.

For each crop, the active ingredient dosage per super group was averaged for the three countries and then used as a weight to define the pesticide use intensity of each pesticide supergroup for each crop. This was done by indexing the supergroup dosage of all crops to the crop with the highest average dosage from our three sample countries. This means that the indexed weight value of the crop with the largest a.i. per supergroup/ha would be the largest and would reduce for all other crops relative to their standing to the crop with the largest pesticide dosage.

These weights ere integrated to the harvested area to calculate the weighted share of pesticide use per super group per crop (kg a.i. supergroup/ha).

Step 3: Definition of active ingredient "cocktail" per super group.

Having defined the amount of active ingredient per super group per hectare of crop, next step was to spread the amount used per super group into specific active chemical ingredients. The number of possible chemical ingredients per pesticide supergroup is enormous, but in practice there are only a few in each supergroup which are regularly and widely used. These regularly and widely used chemical substances are the best estimate when modeling pesticide use. We decided to follow an 80/20 approach, identifying the chemical active substances covering the 80% of the substances most used per pesticide supergroup and define them as our "base cocktail".

To establish the active substance base cocktail for each super group, we turned again to France (AGRESTE, 2018), The Netherlands (CBS, 2018) and the United States (USDA-NASS, 2019) national inventory statistics.

These countries report on the total amount of different active substances used (kg) annually for the three major pesticide super groups. Within each country, the top 80% most used active substances were chosen for each supergroup, and then the top 80% ranking substances for each country were grouped and adjusted for country size and pesticide use to obtain the top 80% most used active substances per supergroup.

Once a preliminary cocktail for each super group was defined, the active substances have to be matched with substances and characterization factors in SimaPro. For all herbicide active substances a SimaPro equivalent name with a characterization factor was found, for Fungicide active substances, only sulfur had no characterized equivalent and was taken from the final mix, for insecticides, spinosad, flonicamid, spirotetramat, sulfur, tefluthrin and chlorantraniliprole, were not fond appropriate SImaPro equivalents with a characterization factor.

Small percentages of each active substance were used, so it was decided not to make any replacement or use other substances as proxies.

Once the final substances per supergroup were identified, the share of each active substance was re-calculated to 100% to define our base active chemical substance per super group.

The resulting default cocktails are shown in Table 0-1 for each pesticide supergroup.

Table 0-1 Share of active ingredients per pesticide super group [%]. I Herbicide basic cocktail, II Insecticide basic cocktail, III Fungicide basic cocktail.

Active ingredients	Share for Herbicides I
Glyphosate	43%
S-Metolachlor	15%
Prosulfocarb	7%
Metamitron	6%
Pendimethalin	5%
Aclonifen	4%
Diquat Dibromide	3%
Atrazine	3%
Chloridazon	2%
Isoproturon	2%
Terbuthylazine	1%
Ethofumesate	1%
Metribuzin	1%
2,4-D,	1%
Linuron	1%
Metazachlor	1%
Napropamide	1%
Chloroprofam	1%
Mcpa	1%

Active ingredients	Share for Insecticides II
Chlorpyrifos	26%
Pirimicarb	14%
Ethoprofos	9%
Acephate	8%
Bifenthrin	8%
Methiocarb	7%
Lambda Cyhalothrin	5%
Oxamyl	5%
Indoxacarb	3%
Cypermethrin	3%
Pyriproxyfen	2%
Methomyl	2%
Imidacloprid	2%
Propargite	2%
Carbaryl	2%

Active ingredients	Share for Fungicides III
Mancozeb	55%
Chlorothalonil	15%
Captan	9%
Propamocarb	7%
Copper	5%
Tebuconazole	2%
Maneb	2%
Azoxystrobin	2%
Folpet	2%
Propiconazole	1%
Epoxiconazole	1%

For European countries, EU restrictions are considered (European Commission, 2019), and the following chemical active substances were excluded, re-adjusting the rest of the mix per supergroup to 100%.

Table 0-2 List of "Not Approved" substances in EU. Status under Status under Reg. (EC) No 1107/2009.

Region	Super group	Restricted active ingredients
EU	Fungicide	Maneb
EU	Insecticide	Acephate
EU	Insecticide	Propargite
EU	Insecticide	Carbaryl
EU	Herbicide	Atrazine
EU	Herbicide	Isoproturon
EU	Herbicide	Linuron

Emission compartments

During the Product Environmental Footprint project, a consensus was reached on an appropriate division of pesticides emissions to different compartments. The paper of Van Zelm, Larrey-Lassalle, & Roux (2014) gives a good overview of the emission routes of pesticides and how they enter the fate modelling applied in the impact assessment method. The following division of emissions was proposed in the PEF guidance document, and this is adopted also in Agri-footprint:

- 90% to agricultural top soil
- 1% to fresh water
- 9% to air

It should be realized that both the 1% to water and the 9% to air can be considered as a first default estimate but actual emissions may differ greatly per type of active ingredient, environmental conditions at application, application technology, climate conditions, (existing) drainage system, crop height, local regulations on applications to reduce emissions.

Table 0-3 Example of pesticide inventory; Soy bean cultivation in Argentina, based on Agri-footprint 5.0 pesticide modelling.

Type of pesticide	Name	Application rate (kg a.i. per ha)
Fungicide	Mancozeb	0.163

Fungicide	Chlorothalonil	0.045
Fungicide	Captan	0.027
Fungicide	Propamocarb	0.019
Fungicide	Copper	0.015
Fungicide	Tebuconazole	0.007
Fungicide	Maneb	0.005
Fungicide	Azoxystrobin	0.005
Fungicide	Folpet	0.005
Fungicide	Propiconazole	0.002
Fungicide	Epoxiconazole	0.002
Insecticide	Chlorpyrifos	0.064
Insecticide	Pirimicarb	0.034
Insecticide	Ethoprofos	0.023
Insecticide	Acephate	0.021
Insecticide	Bifenthrin	0.019
Insecticide	Methiocarb	0.018
Insecticide	Lambda Cyhalothrin	0.012
Insecticide	Oxamyl	0.012
Insecticide	Indoxacarb	0.008
Insecticide	Cypermethrin	0.008
Insecticide	Pyriproxyfen	0.006
Insecticide	Methomyl	0.006
Insecticide	Imidacloprid	0.006
Insecticide	Propargite	0.006
Insecticide	Carbaryl	0.006
Herbicide	Glyphosate	1.117
Herbicide	S-Metolachlor	0.405
Herbicide	Prosulfocarb	0.190
Herbicide	Metamitron	0.154
Herbicide	Pendimethalin	0.144
Herbicide	Aclonifen	0.095
Herbicide	Diquat Dibromide	0.091
Herbicide	Atrazine	0.075
Herbicide	Chloridazon	0.054
Herbicide	Isoproturon	0.041
Herbicide	Terbuthylazine	0.036
Herbicide	Ethofumesate	0.036
Herbicide	Metribuzin	0.032
Herbicide	2,4-D,	0.030
Herbicide	Linuron	0.029
Herbicide	Metazachlor	0.028
Herbicide	Napropamide	0.023
Herbicide	Chloroprofam	0.021
Herbicide	Mcpa	0.019

Appendix C. List of crop and country combinations

Table C-1:List of crops and countries combinations in Agri-footprint

Crop	Countries
Barley grain	AR, AT, AU, BE, BG, CA, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, NO, PL, PT, RO, RU, SE, SI, SK, UA, US
Beans, dry	AR, CA, ET, FR, GR, IE, IT, NL, PL, RO, US, ZA
Beans, green	DE, EG, ES, FR, KE, MA, NL
Broad beans	AU, DE, FR, GB, IT
Cabbages	ES, NL
Carrots and turnips	BE, NL
Cassava	BR, IN, TH, VN
Cauliflowers and broccoli	ES, FR, NL
Chick peas	AR, AU, IN, RU, TR, US
Chicory roots	BE, NL
Cottonseed/Cotton lint	US-AL, US-AR, US-AZ, US-CA, US-GA, US-LA, US-MO, US-MS, US-NC, US-SC, US-TN, US-TX
Fodder beet	NL
Groundnuts, with shell	AR, AU, BR, CN, EG, ID, IN, MX, SD, SN, TH, TR, UG, US-AL, US-FL, US-GA, US-NC, US-TX, VN, ZA
Lentils	AU, CA
Linseed	AR, AT, BE, BG, BY, CA, CN, CZ, DE, DK, ES, FR, GB, HU, IN, IT, LT, LV, PL, RO, RU, SE, SK, UA, US
Lucerne	ES, IT
Lupins	AU, DE, PL
Maize	AR, AT, BE, BG, BR, CA, CH, CN, CZ, DE, ES, FR, GR, HU, ID, IN, IT, LT, MX, NL, PH, PK, PL, PT, RO, RU, SI, SK, TH, TR, UA, US-CO, US-GA, US-IA, US-IL, US-IN, US-KS, US-KY, US-MI, US-MN, US-MO, US-NC, US-ND, US-NE, US-NY, US-OH, US-PA, US-SC, US-SD, US-TX, US-WI, VN, ZA, NL
Mustard seed	CA, CZ, DE, RU, UA
Oat grain	AT, BE, BG, CA, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, NO, PL, PT, RO, SE, SI, SK, UA, US-KS, US-MI, US-MN, US-ND, US-NE, US-NY, US-PA, US-SD, US-WI
Onions, dry	FR
Peas, dry	AT, AU, BE, BG, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, PL, RO, RU, SE, SI, SK, UA, US
Peas, green	BE, DE, EG, FR, GB, NL, ZA
Pigeon peas	IN

Crop	Countries
Potatoes	AT, BE, BG, CA, CH, CN, CY, CZ, DE, DK, EE, EG, ES, FI, FR, GB, GR, HU, IE, IN, IT, LT, LV, NL, NO, PL, PT, RO, RU, SE, SI, SK, TR, US
Rapeseed	AR, AT, AU, BE, BG, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GB, HU, IE, IN, IT, LT, LV, NL, NO, PL, RO, RU, SE, SI, SK, UA, US
Rice	AR, BG, BR, CN, EG, ES, FR, GR, HU, IN, IT, KH, MM, PK, PT, RO, RU, TH, TR, US-AR, US-CA, US-LA, US-MO, US-MS, US-TX, US, UY, VN
Rye grain	AT, BG, BY, CA, CH, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, NO, PL, PT, RO, RU, SE, SK, UA, US
Sesame seed	IN, MX, PK, TR
Sorghum grain	AR, AU, EG, IN, MX, RU, UA, US, ZA
Soybeans	US-AR, US-IA, US-IL, US-IN, US-KS, US-KY, US-LA, US-MD, US-MI, US-MN, US-MO, US-MS, US-NC, US-ND, US-NE, US-OH, US-PA, US-SD, US-TN, US-VA, US-WI, AR, AT, BG, BR, CA, CH, CN, CZ, DE, ES, FR, GR, HU, IN, IT, JP, MX, PY, RO, RU, SI, SK, TR, UA, VN
Spinach	BE, NL
Sugar beet	AT, BE, CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, LT, NL, PL, RO, RU, SE, UA, US
Sugar cane	AR, AU, BR, CN, CO, ID, IN, MX, PK, SD, TH, US
Sunflower seed	AR, AT, AU, BG, CA, CH, CN, CZ, DE, EG, ES, FR, GR, HU, IN, IT, PL, RO, RU, SK, TR, UA, US
Triticale grain	AT, BE, BG, CH, CZ, DE, DK, EE, ES, FR, GB, HU, LT, LV, NL, NO, PL, PT, RO, SE, SI, SK
Wheat grain	AR, AT, AU, BE, BG, BR, CA, CH, CN, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IN, IT, LT, LV, MX, NL, NO, PK, PL, PT, RO, RU, SE, SI, SK, TR, UA, US, US-MT, US-ND, US-ID, US-MN, US-MT, US-ND, US-OR, US-SD, US-WA, US-AR, US-CO, US-DE, US-GA, US-ID, US-IL, US-KS, US-KY, US-MI, US-MN, US-MO, US-MS, US-MT, US-NC, US-ND, US-NE, US-OH, US-OK, US-OR, US-PA, US-SD, US-TX, US-WA
Coconuts	ID, IN, PH
Oil palm fruit	ID, MY, TH
Grass	IE, NL

Appendix D. DQR rating of cultivation

Table D-1: DQR legend table.

	Activity data				Production		Combustion/Conversion	
Score	P	TiR	TeR	GR	Tir	Ter	Tir	Ter
1	Measured/calculated and verified	The data (collection date) can be maximum 2 years old with respect to the "reference year" of the dataset.	Technology aspects have been modelled exactly as described in the title and metadata. without any significant need for improvement	The processes included in the dataset are fully representative for the geography stated in the “location” indicated in the metadata	The "reference year" of the tendered dataset falls within the time validity of the secondary dataset	Technology aspects have been modelled exactly as described in the title and metadata. without any significant need for improvement	The "reference year" of the tendered dataset falls within the time validity of the secondary dataset	Technology aspects have been modelled exactly as described in the title and metadata. without any significant need for improvement
2	Measured/calculated/literature and plausibility checked by reviewer	The data (collection date) can be maximum 4 years old with respect to the "reference year" of the dataset.	Technology aspects are very similar to what described in the title and metadata with need for limited improvements. For example: use of generic technologies’ data instead of modelling all the single plants.	The processes included in the dataset are well representative for the geography stated in the “location” indicated in the metadata	The "reference year" of the tendered dataset is maximum 2 years beyond the time validity of the secondary dataset	Technology aspects are very similar to what described in the title and metadata with need for limited improvements. For example: use of generic technologies’ data instead of modelling all the single plants.	The "reference year" of the tendered dataset is maximum 2 years beyond the time validity of the secondary dataset	Technology aspects are very similar to what described in the title and metadata with need for limited improvements. For example: use of generic technologies’ data instead of modelling all the single plants.

3	Measured/calculated/literature and plausibility not checked by reviewer OR Qualified estimate based on calculations plausibility checked by reviewer	The data (collection date) can be maximum 6 years old with respect to the "reference year" of the dataset.	Technology aspects are similar to what described in the title and metadata but merits improvements. Some of the relevant processes are not modelled with specific data but using proxies.	The processes included in the dataset are sufficiently representative for the geography stated in the ""location" indicated in the metadata. E.g. the represented country differs but has a very similar electricity grid mix profile.	The "reference year" of the tendered dataset is maximum 3 years beyond the time validity of the secondary dataset	Technology aspects are similar to what described in the title and metadata but merits improvements. Some of the relevant processes are not modelled with specific data but using proxies.	The "reference year" of the tendered dataset is maximum 3 years beyond the time validity of the secondary dataset	Technology aspects are similar to what described in the title and metadata but merits improvements. Some of the relevant processes are not modelled with specific data but using proxies.
4	Qualified estimate based on calculations. plausibility not checked by reviewer	The data (collection date) can be maximum 8 years old with respect to the "reference year" of the dataset.	Technology aspects are different from what described in the title and metadata. Requires major improvements.	The processes included in the dataset are only partly representative for the geography stated in the "location" indicated in the metadata. E.g. the represented country differs and has a substantially different electricity grid mix profile	The "reference year" of the tendered dataset is maximum 4 years beyond the time validity of the secondary dataset	Technology aspects are different from what described in the title and metadata. Requires major improvements.	The "reference year" of the tendered dataset is maximum 4 years beyond the time validity of the secondary dataset	Technology aspects are different from what described in the title and metadata. Requires major improvements.
5	Rough estimate with known deficits	The data (collection date) is older than 8 years with respect to the "reference year" of the dataset.	Technology aspects are completely different from what described in the title and metadata. Substantial improvement is necessary	The processes included in the dataset are not representative for the geography stated in the ""location" indicated in the metadata.	The "reference year" of the tendered dataset is more than 4 years beyond the time validity of the secondary dataset	Technology aspects are completely different from what described in the title and metadata. Substantial improvement is necessary	The "reference year" of the tendered dataset is more than 4 years beyond the time validity of the secondary dataset	Technology aspects are completely different from what described in the title and metadata. Substantial improvement is necessary

Table D-2: Rating of cultivation activity data in Agri-Footprint 5.0

	Source	P	TiR	TeR	GR
Yield	Based on most recent data available from FAOstat (5 years average). 2012-2016. (http://www.fao.org/faostat/en/#data/QC)	Data are considered to be measured and reviewed on plausibility by countries that provide them: → 2	Most recent data maximum 2 years old with respect to reference year of 2016. → 1	Data fully comply to meta data description → 1	Data are representative for countries and specific regions → 1
Allocation	FAO LEAP feed guidelines 2014. original data are collected over period 2007-2011. p95	LEAP report is externally reviewed → 2	Data concern 2007-2011 → 2	Data fully comply to meta data description 1	Data are well representative for countries although collected on higher scale level →2
Fuel use	Fuel use from energy model for cultivation (van Paassen et al., 2018)	Calculated per crop. Data available to be reviewed → 2	Different sources used for the underlying data (2018, 2016, 2014, 2005) → 2	Fuels is similar to meta description → 2	Data are representative for countries and specific regions → 1
Electricity	Fuel use from energy model for cultivation (van Paassen et al., 2018)	Calculated per crop. Data available to be reviewed → 2	Different sources used for the underlying data (2018, 2016, 2014, 2005) → 2	Data are similar to meta description → 2	Data are well representative for countries although some proxies are used for countries →2
Fertilizer use	Fertilizer use is a combination of three types of information. 1. Fertilizer application rates per crop country. from Pailliere 2011. Rosas 2011 and Fertistat FAO 2011; 2 Fertilizer types (e.g e.g. Urea. NPK compounds. super triple phosphate etc.) per country IDA 2012. 3. Heavy metals composition of fertilizers are from literature (Mels et al 2008) (Does not concern use right? Or is the effect included?) 4. N2O emissions based on IPCC (2006)	All data sources are measured/calculated or from literature and plausibility checked → 2	Collected data from 2016, 2014 and 2016. Maximum 2 years from reference year → 1	Data fully comply to meta data description → 1	Data are well representative for countries although the allocation to crops could be improved → 2
Organic fertilizer use	1. Manure application rates per country come from FAO stat.	Data are considered to be measured and reviewed on	Data collected from 2014. 2 years from reference year → 1	Data fully comply to meta data description	Data are representative and specific for all countries and regions → 1

	based on 5 year average (2010-2014) 2. Heavy metals composition of manure are from literature (Amlinger et al 2014)	plausibility by countries that provide them: → 2		Although need for improving the allocation to different crops → 2	
Lime use	From different sources. Feed print cultivation documents (2012) and additional work thereafter. Heavy metals composition of lime is from literature (Mels et al 2008). Carbon dioxide emissions based on IPCC (2006)	Based on qualified estimations → 4	Data from 2012 and 2008. on average 6 years from reference year → 3	Technology aspects similar as described in the metadata → 2	The lime processes are sufficiently representative for the geographical locations → 3
Seed use	Seed application rates per country from FAO stat. based on 5 year average (2009-2013). Other sources are used as well	Data are considered to be measured and reviewed on plausibility by countries that provide them: → 2	Most recent data from 2014. 2 years older than reference years, other sources → 2	Technology aspects similar as described in the metadata. → 3	Seeding rates are fully representative for the geography stated in the location → 1
Pesticides use	Pesticide statistics derived from FAOStat	Most data from specific country. Methodology applied to differentiate between crops → 2	Most recent data collected on pesticides use (2012-2016). → 1	Technology are similar as described in the metadata. → 2	Data representative for specific region. → 1
Water use for irrigation	Water use for irrigation is based on the “Blue water footprint” (Mekonnen & Hoekstra. 2010)	Water footprint data from literature concerning specific crop and country. Plausibly checked by reviewer. → 2	Data from 2005. 10 years older than reference year → 5	Blue water footprint very similar to what described in metadata with limited need for improvements → 2	All water footprints are country and region specific and therefore fully representative → 1
Depreciation capital goods	Depreciation of capital goods derived from various capital goods. using Dutch data (Wageningen UR, 2015c)	Depreciation of capital goods form literature possibly not checked by reviewer → 4	Data from 2015. 1 year older than reference year → 1	Technology aspects are very similar to what described in the meta data → 2	The processes included in the dataset are sufficiently representative for various geographies → 3

Appendix E. Rating of production data of AFP

Table E-1:Rating of cultivation activity data from AFP for countries (except France)

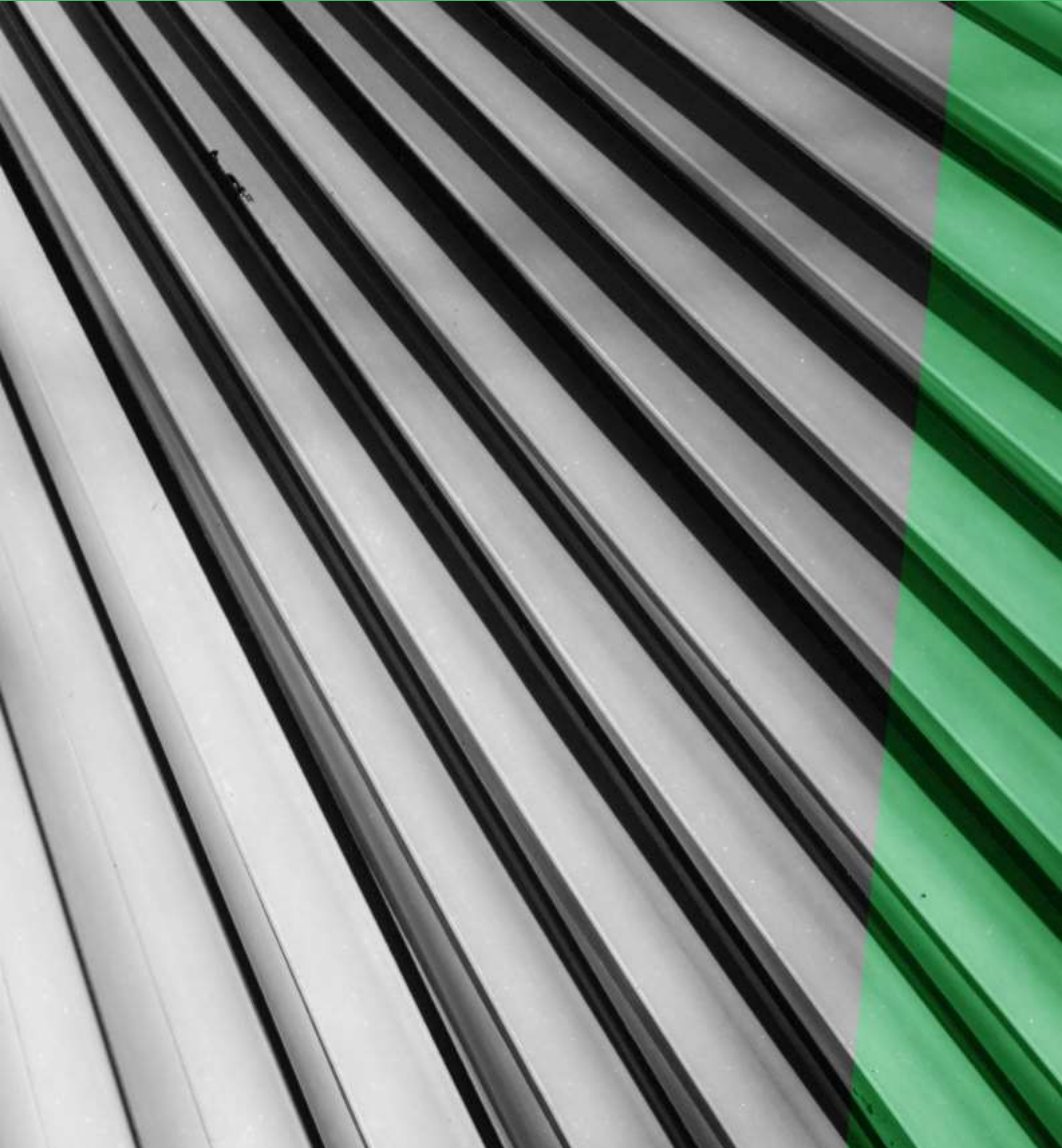
	Source	TiR	TeR
Fuel production & emissions	Fuel production based on ELCD background data for diesel. Emissions based on method for calculating emissions of transport in the Netherlands (Klein et al.. 2012)	Most important background data processes derived from ELCD – data validation till 2015. → 2	Fuel production and emissions have been modelled very similar as described by source → 2
Fertilizer production	Most important and commonly applied fertilizers from Kongshaug (2003). Other minor fertilizer inputs based on older data.	Background data over 10 years old. → 5	Fertilizer production has been modelled similar as described by sources but merits improvements → 3
Organic fertilizer production	Manure is considered to be a waste product. Therefore no emissions on production. Data quality on TiR and TeR are therefore not considered.	NA	NA
Lime production	Lime production is based on crushed stone process from ILCD background data only. Because of this the data quality was considered not to be relevant.	NA	NA
Seed production	Seed production based on cultivation process of that specific crop with yield correction. Data quality scores incorporated in the activity data and therefore not considered here.	NA	NA
Pesticides production	Pesticide production mainly based on Green (1987) with additional emissions to air and water.	Background data over 10 years old. → 5	Pesticide production has been modelled similar as described by sources but merits improvements → 3
Water use for irrigation	Water extracted from the environment and therefore no impacts assigned to the water itself.	NA	NA
Production of capital goods	Production process of tractor based on EPD Volvo truck (Volvo. 2012). Production process of other machinery based on the same process with the exclusion of some materials. Basic infrastructure based on concrete inputs.	Main data sets for the production of capital goods are from 2012. Using background database that fall within the time validity of secondary datasets. → ([2+1]/2=) 1.5	Capital good production and emissions have been modelled similar as described by sources → 2

Appendix F. Baseline rating cultivation

In the tab below the values are used for the baseline DQR rating of the activity data and background data of cultivation processes

Table F-1: Baseline (worst case) rating of cultivation data in Agri-footprint

	Activity data						Production inputs		Combustion			
	Weight	P	TiR	TeR	GR	Average	Tir	Ter	Tir	Ter	Average	DQR weighted average
Yield	13%	2	1	1	1						1.25	0.16
Allocation	3%	2	1	1	2						1.50	0.04
Fuel Use	11%	2	2	2	1	2.25			2	2	1.89	0.22
Electricity	7%	2	2	2	2	2					2.00	0.13
NPK	44%	2	1	1	2		5	3			2.33	1.02
Organic fertilizer	9%	2	1	2	1		NA	NA			1.50	0.14
Lime use	3%	4	3	2	3		NA	NA			3.00	0.08
Seed use	1%	2	2	3	1		NA	NA			2.00	0.02
Pesticides use	4%	2	1	2	2		5	3			2.50	0.09
Water use for irrigation	2%	2	5	2	1		NA	NA			2.50	0.04
Capital goods	5%	4	1	2	3		1.5	2			2.25	0.12
DQR weighted average		2.15	1.31	1.42	1.72		1.61	1.25	2.00	2.00		2.05



Agri-footprint is a high quality and comprehensive life cycle inventory (LCI) database, focused on the agriculture and food sector. It covers data on agricultural products: feed, food and biomass and is used by life cycle assessment (LCA) practitioners. In total the database contains approximately 11,000 products and processes. In the last years Agri-footprint is widely accepted by the food industry, LCA community, scientific community and governments worldwide and has been critically reviewed.

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