Agri-footprint 4.0

Part 2: Description of data

DATE: 14-12-2017

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 8,500 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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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 3rd 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. 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; the cultivation of crops (chapter 3), the processing of those crops and animal products in to food and feed (chapter 5), animal systems (chapter 6), and background processes (chapter 7).

2 What's new?

2.1 Agri-footprint 4.0

1. **Addition of US crop cultivation data:** Crop production inventories are included, using Agri-footprint methodology but based on activity data extracted from USDA LCA commons (see section 4)
2. **Small additions and bug fixes:** Correction of small errors. Some market mixes had incorrect quantities of inputs, resulting in incorrect mass balances. Land occupation flows were missing from some crop production processes.

2.2 Agri-footprint 3.0

The following things were added in Agri-footprint version 3.0:

1. **Production of pesticides:** Life cycle inventories (LCIs) for the production of pesticides were added. Three different types of LCIs were generated; LCI's for the production of specific pesticides, for specific pesticide families and for pesticide families. See section 7.6.
2. **Production of capital goods:** LCIs for the production of tractors, basic farm infrastructure and storage silos are now included in Agri-footprint, and linked to the crop inventories. See section 7.7.
3. **Expansion of scope for crops:** The global coverage of the production of crops has been expanded (i.e. more crop country combinations).
4. **Expansion of processing scope:** Amongst others groundnut processing, ethanol production, fish meal and oil production are now included.
5. **Inclusion of more company specific data:** Data for the production of humic acid from Vitens are now included in the database.
6. **Small additions and bug fixes:** Correction of small errors. Addition of transport of goods to the farm.
7. **Updates of background data:** Most recent FAO statistics for crop yields, and manure application, most recent land use change tool, IFA statistics on fertilizer consumptions in countries.

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

	AFP 1.0	AFP 2.0	AFP 3.0	AFP 4.0
Crops	30	300+	1000+*	1350+*
(Intermediate) products from processing	100	200	500	500
Feed compounds	80	80	80	80
Food products	35	86	163	163
Animal production systems	4	4	4	4

* 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 on a country basis and based on publicly available sources. It has been updated to most recent publicly available data during the development of Agri-footprint 3.0. For the crop cultivation model in Agri-Footprint, the following aspects are taken into account:

- Crop yield (kg crop product / ha cultivated)
- Energy inputs (type and quantity / ha cultivated)
- Land use change (m^2/ ha cultivated)
- Land use change related emissions:
    - Carbon dioxide emissions
- Water use (m^3/ ha cultivated)
- Artificial fertilizer, pesticides and lime inputs (type and application rate / ha cultivated)
- Animal manure inputs (type and application rate / Ha cultivated)
- Fertilizer / manure related emissions:
    - Nitrous oxide emissions
    - Carbon dioxide emissions (from lime and Calcium Ammonium Nitrate (CAN))
    - Ammonia and nitrate emissions
    - Heavy metal emissions.
- Emissions from pesticides application (type and kg active ingredient / Ha cultivated)

During the development of Agri-footprint 1.0, the original crop cultivation data from (Marinussen et al., 2012a-e) were taken as a basis. For Agri-footprint 2.0, the model has been re-developed and updated to cover more crops and countries, to use the most up-to-date statistics, and to allow for specific cultivations (e.g. different rice cultivation practices or crop varieties). This model was further extended in Agri-footprint 3.0 and further aligned to the PEF methodology.

Crop yields were derived from FAO statistics (FAO, 2016). Fertilizer application rates (in terms of N, P and K requirements) were generally derived from Pallière (2011) and Rosas (2011), for some crops, specific literature values were used. Energy use was calculated based on data obtained from the farm simulation tool MEBOT (Schreuder, Dijk, Asperen, Boer, & Schoot, 2008). Land use change has been calculated using the latest version of the land use change tool "Direct Land Use Change Assessment Tool 2016.1" 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. Also, see section 3.2 of this report.

Water use is calculated based on the “blue water” footprint methodology from (Mekonnen & Hoekstra, 2010), and refers to the volume of surface and groundwater consumed as a result of the production of a good, which is further explained in section 3.3.

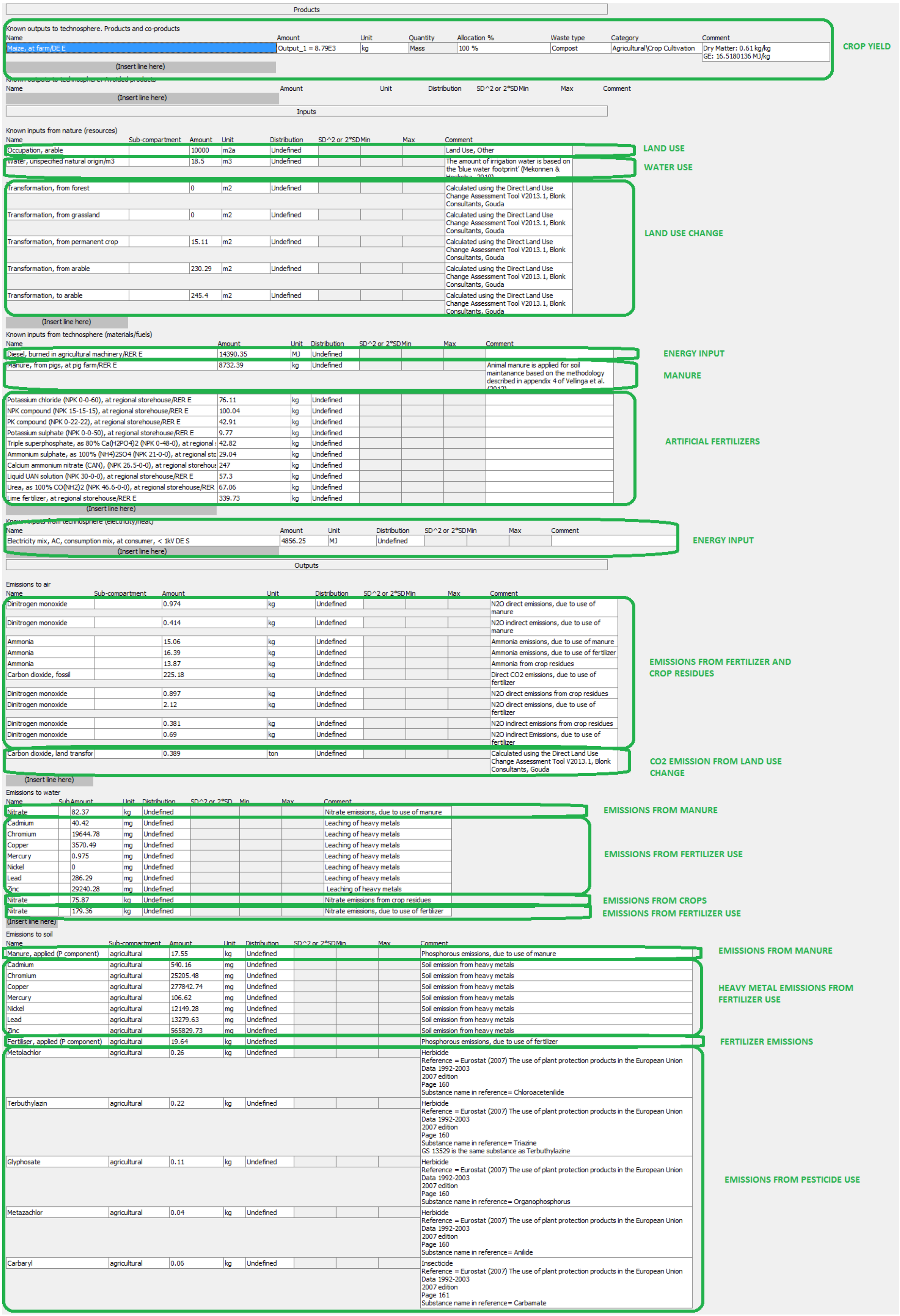
The use of particular fertilizer types per country (e.g. CAN, Urea application rates) has been updated during the development of Agri-footprint and are derived from International Fertilizer Association (IFA) statistics (IFA, 2012). See section 3.4 for further details. The calculation for manure application rates are based on the methodology used in the feedprint study (Vellinga et al., 2013). 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.

Nitrous oxide, carbon dioxide, ammonia and nitrate emissions from lime and fertilizer application are calculated using IPCC guidelines (IPCC, 2006a), which will be summarized in section 3.5.

Heavy metal emissions due to manure and artificial fertilizer application have been calculated, based on an adapted methodology from Nemecek & Schnetzer (2012), using literature concerning heavy metal contents in manure (Romkens & Rietra, 2008) and in fertilizers (Mels, Bisschops, & Swart, 2008), see section 3.6.

Pesticide emissions are derived from a large volume of literature sources and specific to the crop-country combinations. Section 3.7 describes the process in more detail.

All crop cultivation processes are modelled using an identical structure, an example of the crop cultivation process card in SimaPro® is shown in Figure 3-1.



Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Waste type	Category	Comment
Maize, at farm/DE E	Output_1 = 8.79E3	kg	Mass	100 %	Compost	Agricultural\Crop Cultivation	Dry Matter: 0.61 kg/kg GE: 16.5180136 MJ/kg

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Occupation, arable		10000	m2a	Undefined				Land Use, Other
Water, unspecified natural origin/m3		18.5	m3	Undefined				The amount of irrigation water is based on the 'blue water footprint' (Mekonnen &
Transformation, from forest		0	m2	Undefined				Calculated using the Direct Land Use Change Assessment Tool V2013.1, Blonk Consultants, Gouda
Transformation, from grassland		0	m2	Undefined				Calculated using the Direct Land Use Change Assessment Tool V2013.1, Blonk Consultants, Gouda
Transformation, from permanent crop		15.11	m2	Undefined				Calculated using the Direct Land Use Change Assessment Tool V2013.1, Blonk Consultants, Gouda
Transformation, from arable		230.29	m2	Undefined				Calculated using the Direct Land Use Change Assessment Tool V2013.1, Blonk Consultants, Gouda
Transformation, to arable		245.4	m2	Undefined				Calculated using the Direct Land Use Change Assessment Tool V2013.1, Blonk Consultants, Gouda

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Diesel, burned in agricultural machinery/RER E	14390.35	MJ	Undefined				
Manure, from pigs, at pig farm/RER E	8732.39	kg	Undefined				Animal manure is applied for soil maintanance based on the methodology described in appendix 4 of Vellinga et al.
Potassium chloride (NPK 0-0-60), at regional storehouse/RER E	76.11	kg	Undefined				
NPK compound (NPK 15-15-15), at regional storehouse/RER E	100.04	kg	Undefined				
PK compound (NPK 0-22-22), at regional storehouse/RER E	42.91	kg	Undefined				
Potassium sulphate (NPK 0-0-50), at regional storehouse/RER E	9.77	kg	Undefined				
Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at regional	42.82	kg	Undefined				
Ammonium sulphate, as 100% (NH4)2SO4 (NPK 21-0-0), at regional stc	29.04	kg	Undefined				
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at regional storehous	247	kg	Undefined				
Liquid UAN solution (NPK 30-0-0), at regional storehouse/RER E	57.3	kg	Undefined				
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at regional storehouse/RER	67.06	kg	Undefined				
Lime fertilizer, at regional storehouse/RER E	339.73	kg	Undefined				

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Electricity mix, AC, consumption mix, at consumer, < 1kV DE S	4856.25	MJ	Undefined				

Outputs

Emissions to air

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Dinitrogen monoxide		0.974	kg	Undefined				N2O direct emissions, due to use of manure
Dinitrogen monoxide		0.414	kg	Undefined				N2O indirect emissions, due to use of manure
Ammonia		15.06	kg	Undefined				Ammonia emissions, due to use of manure
Ammonia		16.39	kg	Undefined				Ammonia emissions, due to use of fertilizer
Ammonia		13.87	kg	Undefined				Ammonia from crop residues
Carbon dioxide, fossil		225.18	kg	Undefined				Direct CO2 emissions, due to use of fertilizer
Dinitrogen monoxide		0.897	kg	Undefined				N2O direct emissions from crop residues
Dinitrogen monoxide		2.12	kg	Undefined				N2O direct emissions, due to use of fertilizer
Dinitrogen monoxide		0.381	kg	Undefined				N2O indirect emissions from crop residues
Dinitrogen monoxide		0.69	kg	Undefined				N2O indirect Emissions, due to use of fertilizer
Carbon dioxide, land transfor		0.389	ton	Undefined				Calculated using the Direct Land Use Change Assessment Tool V2013.1, Blonk Consultants, Gouda

Emissions to water

Name	Sub	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Nitrate		82.37	kg	Undefined				Nitrate emissions, due to use of manure
Cadmium		40.42	mg	Undefined				Leaching of heavy metals
Chromium		19644.78	mg	Undefined				Leaching of heavy metals
Copper		3570.49	mg	Undefined				Leaching of heavy metals
Mercury		0.975	mg	Undefined				Leaching of heavy metals
Nickel		0	mg	Undefined				Leaching of heavy metals
Lead		286.29	mg	Undefined				Leaching of heavy metals
Zinc		29240.28	mg	Undefined				Leaching of heavy metals
Nitrate		75.87	kg	Undefined				Nitrate emissions from crop residues
Nitrate		179.36	kg	Undefined				Nitrate emissions, due to use of fertilizer

Emissions to soil

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Manure, applied (P component)	agricultural	17.55	kg	Undefined				Phosphorous emissions, due to use of manure
Cadmium	agricultural	540.16	mg	Undefined				Soil emission from heavy metals
Chromium	agricultural	25205.48	mg	Undefined				Soil emission from heavy metals
Copper	agricultural	277842.74	mg	Undefined				Soil emission from heavy metals
Mercury	agricultural	106.62	mg	Undefined				Soil emission from heavy metals
Nickel	agricultural	12149.28	mg	Undefined				Soil emission from heavy metals
Lead	agricultural	13279.63	mg	Undefined				Soil emission from heavy metals
Zinc	agricultural	565829.73	mg	Undefined				Soil emission from heavy metals
Fertiliser, applied (P component)	agricultural	19.64	kg	Undefined				Phosphorous emissions, due to use of fertilizer
Metolachlor	agricultural	0.26	kg	Undefined				Herbicide Reference = Eurostat (2007) The use of plant protection products in the European Union Data 1992-2003 2007 edition Page 160 Substance name in reference= Chloroacetenilide
Terbuthylazin	agricultural	0.22	kg	Undefined				Herbicide Reference = Eurostat (2007) The use of plant protection products in the European Union Data 1992-2003 2007 edition Page 160 Substance name in reference= Triazine GS 13529 is the same substance as Terbuthylazine
Glyphosate	agricultural	0.11	kg	Undefined				Herbicide Reference = Eurostat (2007) The use of plant protection products in the European Union Data 1992-2003 2007 edition Page 160 Substance name in reference= Organophosphorus
Metazachlor	agricultural	0.04	kg	Undefined				Herbicide Reference = Eurostat (2007) The use of plant protection products in the European Union Data 1992-2003 2007 edition Page 160 Substance name in reference= Anilide
Carbaryl	agricultural	0.06	kg	Undefined				Insecticide Reference = Eurostat (2007) The use of plant protection products in the European Union Data 1992-2003 2007 edition Page 161 Substance name in reference= Carbamate

Figure 3-1: SimaPro process card example (Maize in Germany).

3.2 Land use change

Fossil CO_2 emissions resulting from direct land use change were estimated using the "Direct Land Use Change Assessment Tool version 2016.1" 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.

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, 2006b).

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.

3.3 Water use in crop cultivation

Water is used for irrigation of crops as well as during processing. The amount of irrigation water is based on the 'blue water footprint' assessment of (Mekonnen & Hoekstra, 2010).

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, 2010). Combined with FAO yields (2008-2012) the blue water footprint is calculated in m^3/ha.

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).

3.4 Artificial fertilizer application rates

The fertilizer inventory in Agri-footprint is a default inventory which uses statistics and aggregate data to estimate application rates for crops in specific regions. For the fertilizer application rates (in terms of kg NPK) applied, the values of the Feedprint reports were used (see the reports listed in section 3.1 for a full list of references). The majority of these fertilizer application rates were derived from data supplied by 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. To match these total N, P and K application rates, to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.), data on regional fertilizer consumption rates from IFA statistics (retrieved January 2017) were used.

Some fertilizers supply multiple nutrient types (for example ammonium phosphate application supplies both N and P to agricultural soil). In IFA statistics, 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 was 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. 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.

3.5 Emissions from managed soils

Nitrogen additions to managed soils result in a number of important emissions that affect global warming, eutrophication and other impact categories. Nitrogen is added to agricultural soils to promote crop growth and gain higher yields. The most common ways of supplying nitrogen to soils is by spreading manure or by using artificial fertilizers. The following sections summarize the calculation procedures for emissions of nitrous oxide (N_2O) (3.5.1), ammonia (NH_3) and nitrate (NO_3^-) emissions (3.5.2) due to nitrogen containing synthetic or organic fertilizer application. Next to nitrogen emissions, there are also CO_2 emissions from urea and lime application (0) and emissions of phosphorous containing elements to soil and water (3.5.4). These soil emissions are modelled separately in Agri-footprint (e.g. N_2O direct emissions due to use of animal manure, N_2O direct emissions from crop residues).

3.5.1 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 pasture land 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;.

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

Equation 3-1 (IPCC, 2006a)

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 3-6 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 3-1 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.

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.

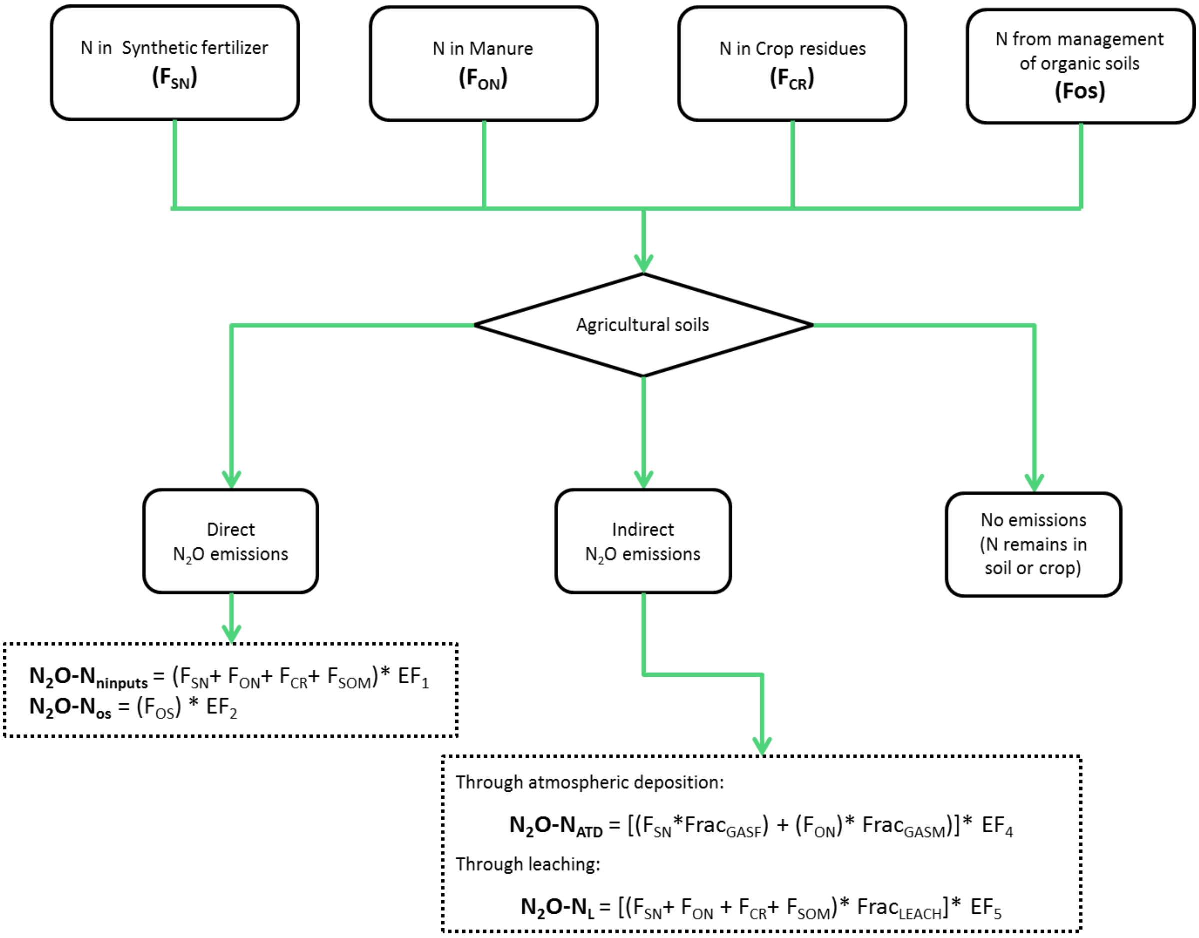


Figure 3-2: Nitrous oxide emission (direct and indirect) from due to different N inputs (IPCC, 2006a).

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, 2006a)

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, $[\frac{kg\ N_2O-N}{kg\ N\ input}]$

As mentioned before, the contribution of F_{SOM} is incorporated in the emissions from land use change, which are calculated elsewhere (see 3.2). F_{CR} is dependent on the type of crop and yield and is determined separately. The IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a) 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 3-1.

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 3.4 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., 2013), 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, 2006a)

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, 2006a)

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, 2006a)

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, $\left[\frac{kg\ N_2O\text{–}N}{kg\ NH_3\text{–}N + NO_x\text{–}N\ volatilized}\right]$
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 3-1. 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, 2006a)

$Frac_{LEACH-(H)}$ = 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, $\left[\frac{kg\ N_2O\text{–}N}{kg\ N\ leached\ and\ runoff}\right]$

3.5.2 Ammonia (NH_3) and nitrate (NO_3^-) emissions from managed soils

Again, the IPCC calculation rules (IPCC, 2006a) were applied to determine the ammonia and nitrate emissions. 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, 2006a)

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, 2006a)

Where,

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

3.5.3 Carbon dioxide (CO_2) emissions from liming and urea application

CO_2 emissions from limestone, dolomite and urea application:

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

Equation 3-9 (IPCC, 2006a)

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 3-1.

3.5.4 Phosphorous emissions from application of synthetic fertilizer and manure

The phosphorous content of synthetic fertilizers and manure is emitted to the soil. Up to version 2 of the Agri-footprint database is was 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.

Table 3-1: 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-	$\left(\frac{62}{14}\right)$

3.6 Emission of heavy metals during cultivation

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 3-2 and Table 3-3, respectively. The deposition of heavy metals is stated in Table 3-4.

Table 3-2: Heavy metal content of fertilizers (Mels et al., 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 3-3: 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 Figure 3-3. 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[1] because cattle systems are often closed systems. The ratio pig / poultry manure is based on FAO data on the amount of available nitrogen per type of animal manure.

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[1] 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.

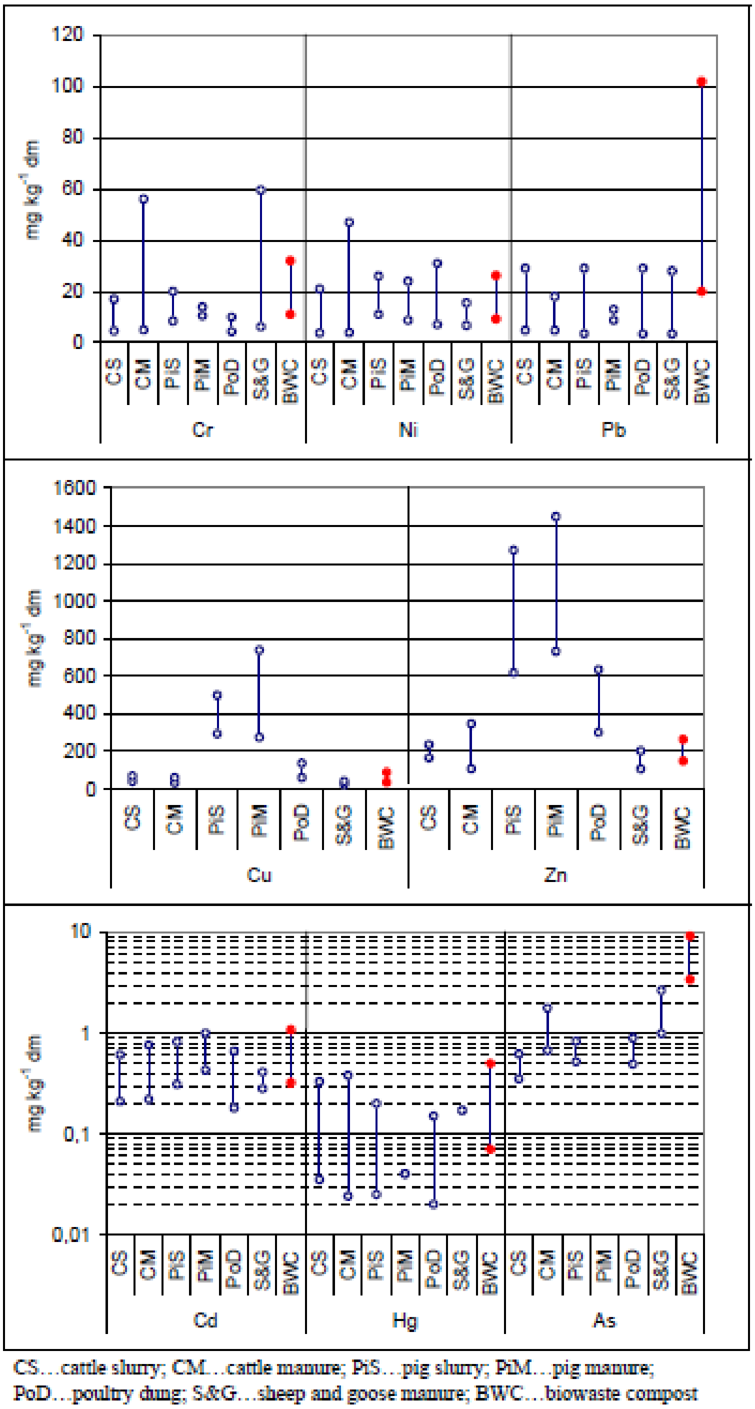

Figure 3-3: Range of heavy metal contents in different animal manures in the EU. CS = Cattle slurry, CM =Cattle manure , PiS =Pig slurry , PiM =Pig manure , PoD = Poulty dung, S&G =Sheep and goat manure , BWC = Biowaste compost (Amlinger et al., 2004)

Table 3-4: 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 3-5. Leaching of heavy metals to ground water is mentioned in Table 3-6.

Table 3-5: 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)
Wheat	0.013	2.280	4.100	0.009	0.860	0.100	24.800
Barley	0.013	2.280	3.900	0.009	0.190	1.000	24.000
Rye	0.013	0.930	3.110	0.009	0.860	0.300	28.800
Oat	0.013	2.280	3.600	0.009	0.860	0.050	24.700
Triticale	0.013	2.280	4.700	0.009	0.860	0.140	34.000
Maize	0.520	0.240	1.600	0.010	0.860	1.300	21.600
Lupine	0.020	1.400	8.000	0.013	0.860	0.400	33.700
Rapeseed	0.020	1.400	4.400	0.013	1.000	0.400	46.500
Pea	0.020	1.400	8.000	0.013	0.860	0.400	33.700
Starch potato	0.030	0.400	1.100	0.003	0.250	0.030	2.900
Sugar beet	0.040	0.220	1.100	0.001	0.094	0.154	6.200
Fodder beet	0.040	0.220	1.100	0.001	0.094	0.154	6.200
Cassava*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Coconut*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Oil palm*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Rice*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Sorghum*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Soybean*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Sugar cane*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Sunflower seed*	0.084	1.203	4.026	0.008	0.760	0.416	25.075
Grass	0.200	0.600	8.400	0.019	3.900	2.250	44.000

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

Table 3-6 : 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:

$$M_{\text{leach i}} = m_{\text{leach i}} * A_{\text{i}}$$

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 3-6)
$\boldsymbol{A_{i}}$ = 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:

$$M_{\text{soil i}} = (\Sigma\text{inputs}_{\text{i}} - \Sigma\text{outputs}_{\text{i}}) * A_{\text{i}}$$

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

$$\Sigma\text{inputs}_{\text{i}} = A * A_{\text{content i}} + B * B_{\text{content i}} + C$$

Equation 3-13

Where,

$\boldsymbol{A}$ = fertilizer application (kg/ha/yr)
$\boldsymbol{A_{content\ i}}$ = heavy metal content i for fertilizer applied (Table 3-2)
$\boldsymbol{B}$ = manure application (kg DM/ha/yr)
$\boldsymbol{B_{content\ i}}$ = heavy metal content i for manure applied (Table 3-3)
C = deposition (Table 3-4)

$$\Sigma\text{outputs}_{\text{i}} = M_{\text{leach i}} + D * D_{\text{content i}}$$

Equation 3-14

Where,

$\boldsymbol{D}$ = yield (kg DM/ha/yr)
$\boldsymbol{D_{content\ i}}$ = heavy metal content i for crop (Table 3-5)

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.

3.7 Pesticide application

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. The pesticide inventory in Agri-footprint is a default inventory which can be used to gain insights in the toxicity impact of biomass taken into account the limitations as reported in this chapter. Primary data (when available) are always preferred over this inventory.

3.7.1 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.
- Most inventories are based on one literature source so variation is not taken into account because in most countries the statistics are not available and literature is far from sufficient.

3.7.2 Inventory development process

It was not possible to develop this inventory from one source such as FAOstat[2] so a thorough literature study is undertaken. The process is described in the following two steps. The pesticide inventory for soybean cultivation in Argentina is provided in Table 3-8 as example.

3.7.3 Step 1: Literature study

The first and was to find appropriate literature for each crop/country combination. The quality differs a lot between crop-country combinations. A high quality source is for instance Garthwaite et al. (2012) in which pesticide usage was collected in 2012 from 24,600 fields throughout the UK. This inventory is a combination of different sources because a complete and robust inventory could not be found. Sometimes no literature is found and a pesticide inventory from another country is assumed (e.g. the Indian sugarcane inventory is used for sugarcane from Pakistan). Literature can roughly be classified in the following 6 classes, ranking from high quality to low quality:

1) National statistics with crop-country pesticide inventories (e.g. Garthwaite et al., 2012).
2) Peer reviewed literature containing crop/country specific pesticide inventories.
3) Reports containing crop/country specific pesticide inventories (Bindraban et al., 2009).
4) Farm enterprise budgets (e.g. New South Wales Department of Primary Industries (NSW DPI, 2012c)).
5) Use of a crop inventory from another country (e.g. Sugarcane from Pakistan).
6) Other sources such as websites.

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[2] FAOstat does not provide pesticide statistics on a crop/country level and only pesticides classes are provided instead of specific active ingredients/substances.

3.7.4 Step 2: Matching substances with known characterization factors

After the literature study, the active substances have to match with substances and characterization factors in SimaPro. The amide fungicide isopyrazam is for instance not included in SimaPro so another amide fungicide has to be selected as replacement trying to take into account;

- Allowed substances in a certain country.
- Allowed substances on a certain crop.
- Availability.

Characterization factors did not exist for approximately 10% of the substances. Most of these substances are not used often. Exceptions are Boscalid, Fenpropidin, Flufenacet, Fosetyl, Haloxyfop, Metconazole, Picoxystrobin which are regularly used.

For the 15 not replaced substances the amount of substance applied was very low or another substance of the same class could not be selected because no characterization factors did exists for any of the substances of this class.

The replacement / exclusion could results in high environmental underestimates. Table 3-7 provides the replaced substances, the reason for replacement and the substance replacement (so the substance in Agri-footprint inventories).

Table 3-7: Replaced substances, the reason for replacement and the substance replacement. I = The substance name in the reference provides a pesticide class instead of a specific substance name. II = The specific substance is not included in the LCIA in scope (ReCiPe and ILCD). Another allowed substance of the same pesticide class is assumed. III = No other substances of the pesticide class are included in LCIA in scope (ReCiPe and ILCD) or the pesticide is unclassified (not included in a pesticide class). The impact of the substance is neglected.

Substance name / pesticide class in reference	Reason for replacement	Substance replacement(s)
Acetochlor	II	Butachlor
Aliphatic nitrogen	I	Cymoxanil
Anilide	I	Metazachlor / Quinmerac
Aromatic fungicides	I	Chlorothalonil
Aryloxyphenoxypropionich	I	Propaquizafop
Benzimidazole	I	Carbendazim
Beta-cypermethrin	II	Alpha-cypermethrin
Bipyridinium	I	Diquat
Bixafen	II	Prochloraz
Boscalid	II	Prochloraz
butroxydim	II	Sethoxydim
Carbamate	I	Carbaryl
carfentrazone	III	*Not replaced*
Chlorantraniliprole	II	Ryanodine
Chloroacetanilide	I	Metolachlor
Clethodim	II	Sethoxydim
Cloransulam-methyl	II	Asulam
Conazole	I	Thiram
Copper chloride oxide, hydrate	II	Copper
Cinidon-ethyl	III	*Not replaced*
Cyprodinil	II	Pyrimethanil
Diclofop	II	Clodinafop-propargyl
Diclosulam	II	*Not replaced*
Diflufenzopyr	II	Fluometuron
Dimethenamid-P	II	Propyzamide
Dinitroaniline	I	Pendimethalin / Metazachlor / Fluazinam
Dithiocarbamate	I	Thiram / Maneb
Ethalfluralin	II	Fluchloralin
Fenpropidin	III	*Not replaced*
Flucarbazone	II	Sulfentrazone
Fludioxonil	II	Fenpiclonil
Flufenacet	II	Diflufenican
Flumetsulam	II	Asulam
Flumioxazin	III	*Not replaced*
Fluoroglycofen-ethyl	II	Fluorodifen
Fluoxastrobin	II	Azoxystrobin
Flupyrsulfuron-methyl	II	Bensulfuron methyl ester
Fluquinconazole	II	Fenbuconazole
Flurtamone	III	*Not replaced*
Flutriafol	II	Epoxiconazole
Fosetyl	II	Edifenphos
Haloxyfop	II	Propaquizafop
Iodsulfuron	II	Triasulfuron
Imazapic	II	Pursuit
Imazamox	II	Imazamethabenz-methyl

Substance name / pesticide class in reference	Reason for replacement	Substance replacement(s)
Jodosulfuron-methyl-natrium	II	Chlorsulfuron
Kasugamycin	II	Streptomycin sesquisulfate
Mefenpyr-diethyl	III	*Not replaced*
Mepiquat	II	Chlormequat
Mepronil	II	Salicylanilide
Metconazole	II	Epoxiconazole
Metosulam	II	Asulam
monalide	II	Propanil
Morpholine	I	Dimethomorph
Mesotrione	II	*Not replaced*
Ofurace	II	Oxadixyl
Organophosphorus	I	Glyphosate
Oxadiargyl	II	Oxadiazon
Oxazole	I	Vinclozolin
Oxime-carbamate	I	Oxamyl
Phenoxy	I	MCPA
Penoxsulam	II	Asulam
Picolinafen	II	Fluroxypyr
Picoxystrobin	II	Azoxystrobin
Prothioconazole	II	Difenoconazole
Pyraclostrobine	II	Azoxystrobin
Pynoxaden	II	*Not replaced*
Pyraflufen	II	*Not replaced*
Quinoline	I	Quinmerac
Quinoxyfen	II	*Not replaced*
Spiroxamine	III	*Not replaced*
Sulcotrione	II	*Not replaced*
Sulfosulfuron	II	Rimsulfuron
Sulfur	II	*Not replaced*
Tebuconazole	II	Difenoconazole
Thiacloprid	II	Imidacloprid
Thiadiazine	I	Bentazone
Thiocarbamate	I	Prosulfocarb
Tralkoxydim	II	Cycloxydim
Tepraloxydim	II	Sethoxydim
Triazine	I	GS 13529
Triazinone	I	Metribuzin
Triazoxide	II	Iprodione
Trifloxystrobin	II	Kresoxim-metil
Triketone	III	Sulcotrion
Tritosulfuron	II	Metsulfuron-methyl

Table 3-8: Example of a pesticide inventory; Soy bean cultivation in Argentina (based on Bindraban et al., 2009).

Type of pesticide	Source name	SimaPro substance	CAS number	Application rate (kg a.i. per ha)
Fungicide	Trifloxystrobin*	Azoxystrobin	131860-33-8	0.065
Fungicide	Cyproconazool	Cyproconazool	094361-06-5	0.025
Herbicide	2,4-D	2,4-D	000094-75-7	0.300
Herbicide	Glyphosate	Glyphosate	001071-83-6	3.840
Herbicide	Cypermethrin	Cypermethrin	052315-07-8	0.075
Insecticide	Chlorpyriphos	Chlorpyriphos	002921-88-2	0.288
Insecticide	Endosulfan	Endosulfan	000115-29-7	0.210

* The strobilurin fungicide trifloxystrobin is not a known substance in SimaPro. The strobilurin fungicide azoxystrobin is assumed as replacement because this substance is known in SimaPro and is available (e.g. Ykatu) for soybeans in Argentina.

3.7.5 Emission compartments

Up to version 2 of the Agri-footprint database, the total amount of a.i. applied is emitted to the agricultural soil compartment. This means that drift, drainage and attachment to vegetation were not taken into account. Depending on the substance, climate, crop and application technique the mode uncertainty can be at least two to three orders of magnitude. This was currently the only feasible modelling method because no agreed default emission fractions are available (Rosenbaum et al., 2015) and not enough detailed information (e.g. buffer zones, application methods, climatically conditions) is available to use a pesticide emission model (like PestLCI 2.0). However, during the Product Environmental Footprint project, a consensus was reached on a more 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.

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

4.1 Introduction

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).

The crop production database contains life cycle inventory data for Cottonseed and cotton lint, groundnuts, maize, oats, rice, soybean and winter, spring and durum wheat for the main producing states within the United States. The data is organized on a state level, and is developed using survey data and statistics. Please refer to the original publication of Cooper et. al. (2012), for a detailed description. In total, 117 crop products and co-products are inventoried.

Table 4-1: Crops and states covered by the USDA LCA commons crops dataset. AL= Alabama, AR= Arkansas, AZ= Arizona, CA= California, CO= Colorado, DE= Delaware, FL= Florida, GA= Georgia, IA= Iowa, ID= Idaho, IL= Illinois, IN= Indiana, KS= Kansas, KY= Kentucky, LA= Louisiana, MD= Maryland, MI= Michigan, MN= Minnesota, MO= Missouri, MS= Mississippi, MT= Montana, NC= North Carolina, ND= North Dakota, NE= Nebraska, NY= New York, OH= Ohio, OK= Oklahoma, OR= Oregon, PA= Pennsylvania, SC= South Carolina, SD= South Dakota, TN= Tennessee, TX= Texas, VA= Virginia, WA= Washington, WI= Wisconsin

Crop	States covered
Maize (corn)	CO, GA, IA, IL, IN, KS, KY, MI, MN, MO, NC, ND, NE, NY, OH, PA, SC, SD, TX, WI
Cotton lint and seed	AL, AR, AZ, CA, GA, LA, MO, MS, NC, SC, TN, TX
Durum wheat	MT, ND
Oats	KS, MI, MN, ND, NE, NY, PA, SD, WI
Groundnuts (peanuts)	AL, FL, GA, NC, TX
Rice	AR, CA, LA, MO, MS, TX
Soybeans	AR, IA, IL, IN, KS, KY, LA, MD, MI, MN, MO, MS, NC, ND, NE, OH, PA, SD, TN, VA, WI
Spring wheat (excluding durum)	ID, MN, MT, ND, OR, SD, WA
Winter wheat	AR, CO, DE, GA, ID, IL, KS, KY, MI, MN, MO, MS, MT, NC, ND, NE, OH, OK, OR, PA, SD, TX, WA

However, the number of datasets in the database is much larger. The data is organized in unit processes with a high level of disaggregation. There are 34211 processes that model field activities, and 1758 cut-off processes. These cut-off processes are 'empty' processes that function as placeholders for inventories that could be added in the future. For example, there is a cut-off process for 'Anti-siphon device, for chemigation, for corn, at farm'. This means that some field activities may have an input of anti-siphon device, but currently no environmental emissions are inventoried for this input. The field activities describe various activities that may occur during crop production, for example 'apply fertilizer, no broadcast, band sprayer, corn, at farm US-MO'.

The number of datasets therefore totals to 36534. Generally, over 300 processes are used to model the cradle to gate inventory of a crop product. While this provides a high-level detail on how the data is constructed, it also provides a challenge during interpretation and navigation through the dataset.

Additionally, the data does not align well to popular life cycle impact assessment methods (LCIA methods), as not all elementary flows are tracked to their endpoints, non-standard substance names are used, and some data is missing due to the use of cut-offs.

The aim of the integration project therefore was to:

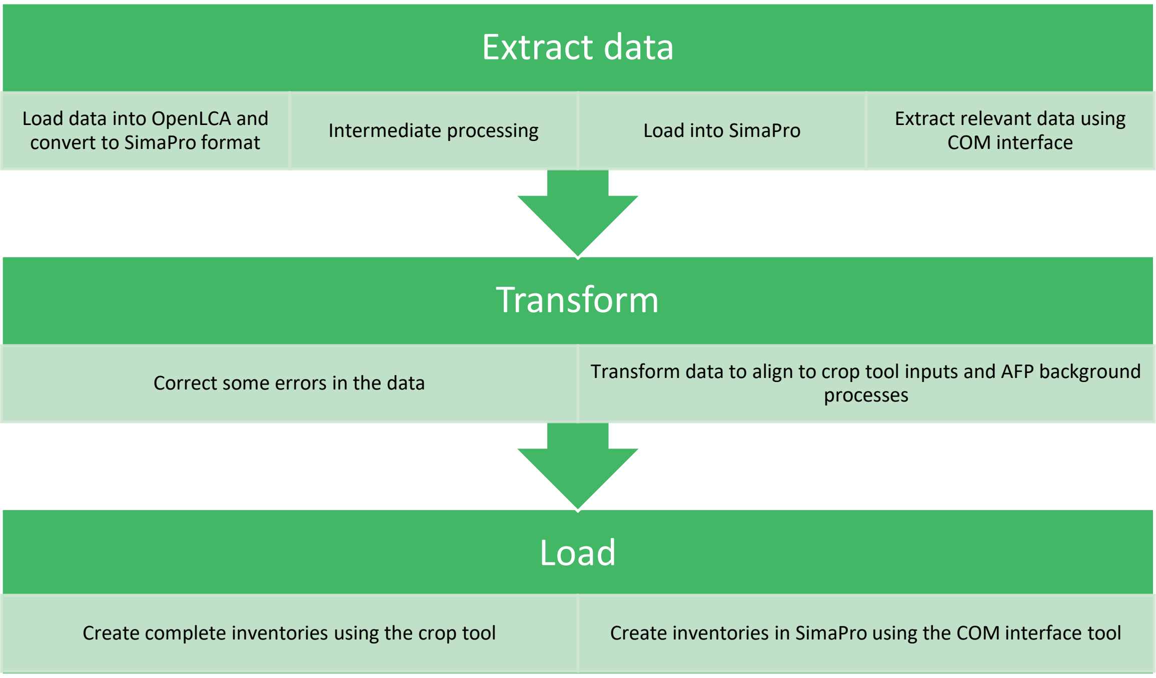
1. Simplify the inventories, by aggregating some of the field activities
2. Connect data to relevant background datasets, when missing
3. Calculate and add relevant elementary flows
4. Restructure data to align better to Agri-footprint structure

4.1.1 Approach taken

There are three main stages that were used to convert the data from its original form to the Agri-footprint format:

1. Extract the relevant activity data from the original database
2. Transform the activity data to a format similar to the other inventories already present in Agri-footprint
3. Load the data into the Agri-footprint crop tool, generate complete LCIs and export them to SimaPro

These steps are described in more detail in the following sections.



4.2 Extracting the data

The original data was provided in an OpenLCA database format. These were loaded into OpenLCA and exported into a SimaPro friendly format. After some minor intermediate processing, these data were then loaded into SimaPro. The data were loaded into SimaPro, because we already have a significant code base and experience to automatically process data in SimaPro, by taking advantage the SimaPro COM interface (Gelder, Moore, & Janssen, 2010). At the time of writing, OpenLCA does not provide a documented interface to manipulate data programmatically.

A wrapper written in Python was used to access the COM interface. This wrapper includes some convenience functions (e.g. initializing a connection to a specific project in SimaPro) and a further abstraction of the low-level functionality provided by the COM interface. For example, it provides functions to load complete datasets into SimaPro directly from a Pandas DataFrame, create lists of all processes in a project, automatically discover the Input type of a project etc.

4.3 Data Transformations

To make the data conform to the Agri-footprint structure, some transformations were applied to the extracted data.

4.3.1 Data corrections

During the extraction of the data, it was discovered that some irrigation energy use data was incorrect. The cause for the error turned out to be an error in one of the calculation steps in the underlying irrigation energy model (in excel). This error was corrected in the Excel model (provided by one of the original dataset creators). Rather than going through the whole data publication process (from USDA LCA commons to OpenLCA to SimaPro) the corrected data were inserted directly into the extracted data, thus replacing the erroneous data points. Some additional errors were discovered during this process (how the energy use was divided between different pump classes did not work correctly), these were corrected too. These modifications result in a divergence from the published data on the LCA commons data hub.

4.3.2 Data aggregation

4.3.2.1 Aggregation of energy use

All fossil fuel based energy inputs for field operations and irrigation were aggregated into a single input. The most dominant fuel input is diesel. As currently, there are no inventories present in Agri-footprint for combustion of natural gas, gasoline and LPG for crop production, these energy inputs were added to the input of Diesel (in MJ). This is not a major cause of concern, as the ‘other’ energy inputs are relatively small compared to the Diesel input. For 109 out of 117 products, the diesel input was higher than 95% of the total fossil fuel input. For only 3 products, was the relative diesel input smaller than 90%.

Electricity was modelled using the average US grid intensity, as no state specific data is available in Agri-footprint. Technology mix and consequent emission profiles vary widely across different US regions. In the future, region specific grid inventories should be used instead.

4.3.2.2 Aggregation of seed inputs

The original data specifies three different seed types (‘unspecified’, ‘GMO herbicide resistant’ and ‘Non-GMO herbicide resistant’). These three types were aggregated into a single seed inputs, as Agri-footprint currently does not make a distinction between GMO and non-GMO crops.

4.3.3 Data mapping

The crop fertilizer inputs could not be directly linked to those available in Agri-footprint. This is mainly because the LCA commons assumes different NPK values of the fertilizer products, or that fertilizer types are used that are not available in Agri-footprint. Table 4-2 provides an overview of how fertilizers from LCA commons were mapped to those available in Agri-footprint. The scaling factor is determined based on the most relevant nutrient component (i.e. for nitrogen fertilizer, the ratio of N content AFP / N content LCA commons fertilizer is used to determine the scaling factor). The nitrogen content is provided in the LCA commons documentation (Cooper, Kahn, & Noon, 2012)

Table 4-2: Mapping from LCA commons fertilizer inputs to AFP inputs

LCA commons fertilizer name	Agri-footprint fertilizer	N (g/kg)	P (g/kg)	K (g/kg)	Scaling factor
nitrogenous fertilizer, ammonium nitrate	Ammonium nitrate	0.335	0	0	0.96
nitrogenous fertilizer, ammonium sulfate	Ammonium sulphate	0.21	0	0	1
nitrogenous fertilizer, anhydrous ammonia	Ammonia direct application	0.82	0	0	1
nitrogenous fertilizer, aqueous ammonia	Ammonia direct application	0.225	0	0	0.27
nitrogenous fertilizer, nitrogen solutions	Nitrogen solutions	0.3	0	0	1
nitrogenous fertilizer, sodium nitrate	Nitrogen solutions	0.16	0	0	0.53
nitrogenous fertilizer, urea	Urea	0.455	0	0	0.98
phosphatic fertilizer, diammonium phosphate	Ammonium phosphate	0.195	0.495	0	0.87
phosphatic fertilizer, monoammonium phosphate	Ammonium phosphate	0.11	0.545	0	0.96
phosphatic fertilizer, other single phosphates	Ground rock direct application	0	0.23	0	0.72
phosphatic fertilizer, superphosphate grades 22% and under	Single superphosphate	0	0.2	0	0.95
phosphatic fertilizer, superphosphate grades over 22%	Triple superphosphate	0	0.48	0	1
potassic fertilizer, other single nutrients	Potassium sulphate	0	0	0.44	0.73
potassic fertilizer, potassium chloride	Potassium chloride	0	0	0.5	1

As similar approach was taken to determine the inputs of animal manure. Here the Nitrogen content of the animal manures was determined by taking average IPCC N losses for the different manure storage types into account (IPCC, 2006c), as Cooper et al. (2012) does not provide sufficient detail.

Table 4-3: Nitrogen, phosphate and Potassium contents of manure (Porg measured as P_2O_5 and Korg as K_2O)

Name	Norg	Porg	Korg
beef manure, from semi-solid to solid storage	0.027	0.008	0.035
beef manure, from slurry storage	0.029	0.008	0.035
beef manure, from unspecified storage	0.028	0.008	0.035
dairy manure, from lagoon storage	0.053	0.022	0.091
dairy manure, from semi-solid to solid storage	0.057	0.022	0.091
dairy manure, from slurry storage	0.049	0.022	0.091
dairy manure, from unspecified storage	0.053	0.022	0.091
hog manure, from lagoon storage	0.045	0.020	0.040
hog manure, from semi-solid to solid storage	0.041	0.020	0.040
hog manure, from slurry storage	0.039	0.020	0.040
hog manure, from unspecified storage	0.041	0.020	0.040
other animal manure, from unspecified storage	0.038	0.017	0.047
poultry manure, from lagoon storage	0.033	0.017	0.023
poultry manure, from semi-solid to solid storage	0.033	0.017	0.023
poultry manure, from slurry storage	0.025	0.017	0.023
poultry manure, from unspecified storage	0.030	0.017	0.023
unspecified animal manure, from unspecified storage	0.038	0.017	0.047

4.4 Loading the data into Agri-footprint

The transformed activity data is then used to generate the crop inventories. The ‘Agri-footprint crop tool’ is used to generate the complete inventories. This tool was developed to generate crop inventories for the Agri-footprint databases and has been in used since Agri-footprint database version 2.0. The crop tool is written in Python, and uses the Pandas library to combine and manipulate datasets in a batch wise fashion (all crop inventories are calculated in parallel). Missing data is added from background sources (for example land use change and land occupation inputs, heavy metal contents of crops and fertilizers). The emissions are calculated using standard Agri-footprint calculation rules and methodology (as described in section 3). The process inputs are linked to already existing Agri-footprint processes (for fertilizer and pesticide productions for example).

The inventories are then loaded into the Agri-footprint library in SimaPro using the COM interface and our custom SimaPro COM wrapper.

4.5 Results and validation

4.5.1 Activity data

To detect potential errors, the activity data was systemically analyzed. The following section provides two types of visualizations; a ‘scatter plot’ to visualize the relation between two parameters, and a ‘violin plot’ to show distributions of parameters for different categories (often crops).

4.5.1.1 Synthetic fertilizer inputs

The figures below show the relation between the synthetic fertilizer inputs (kg per ha) and the yield (kg per ha).

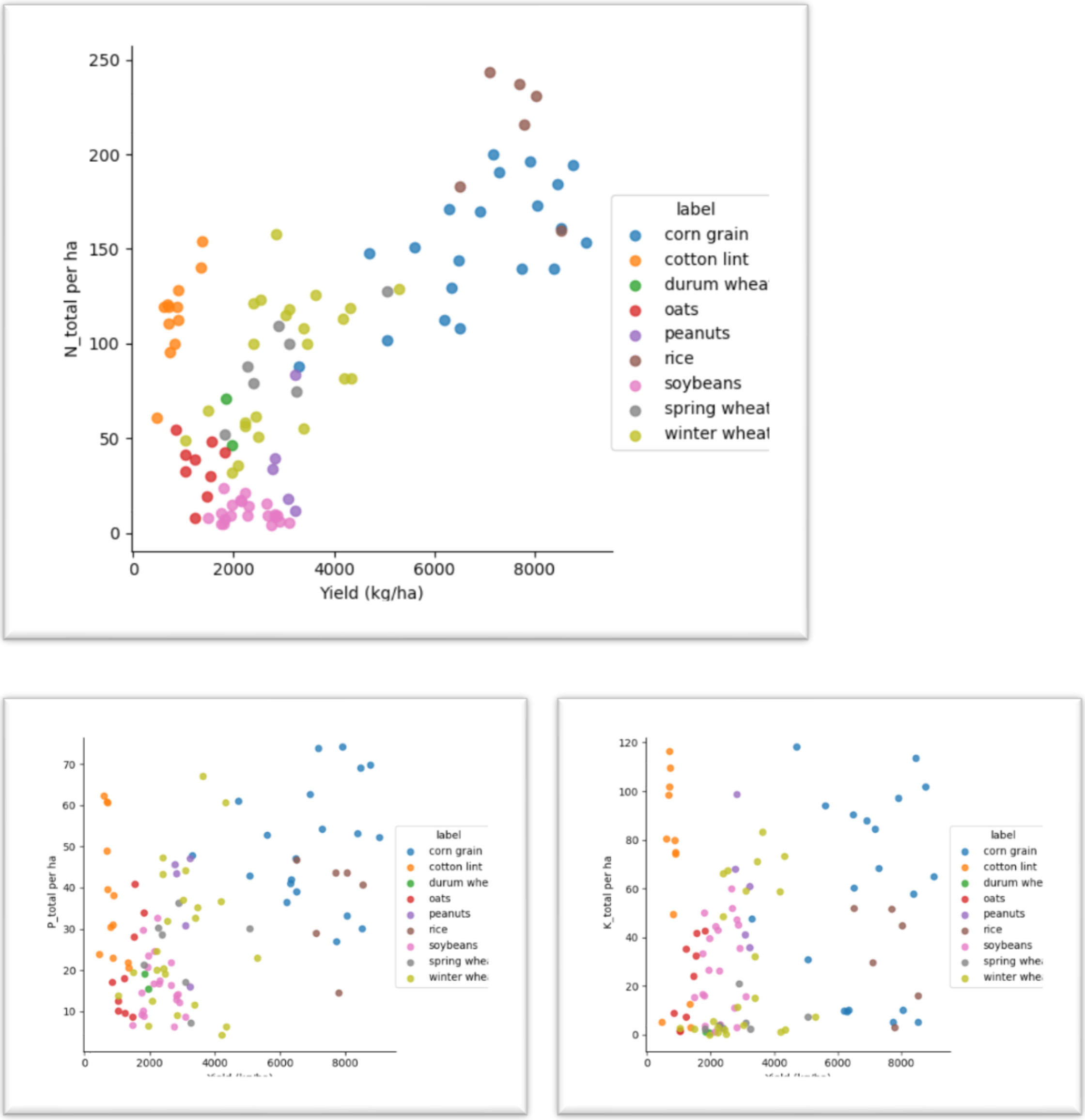


Figure 4-1 (a, b, c): The relation between synthetic N, P and K fertilizers and the yield. Different crop types can be distinguished by the color of the dots.

From Figure 4-1a it can be seen there seems to be a correlation between the yield and the amount of synthetic nitrogen applied. In addition, a clustering of the different crop types can be distinguished. For example, cotton has a relatively high input of Nitrogen, but a relatively low yield. Conversely, soybeans receive a relatively low nitrogen input (as is to be expected). For phosphorus and potassium inputs the relation between input quantity and yield is less strong. Note that there are many factors that influence crop yield beyond fertilization amount.

These factors include climate, soil properties, farm management practices etc. Therefore, no causal relation should be inferred from these figures.

4.5.1.2 Organic fertilizer inputs

Where one could detect a correlation between synthetic fertilizers and yield, this is not the case for the input of organic fertilizers and yield (Figure 4-2).

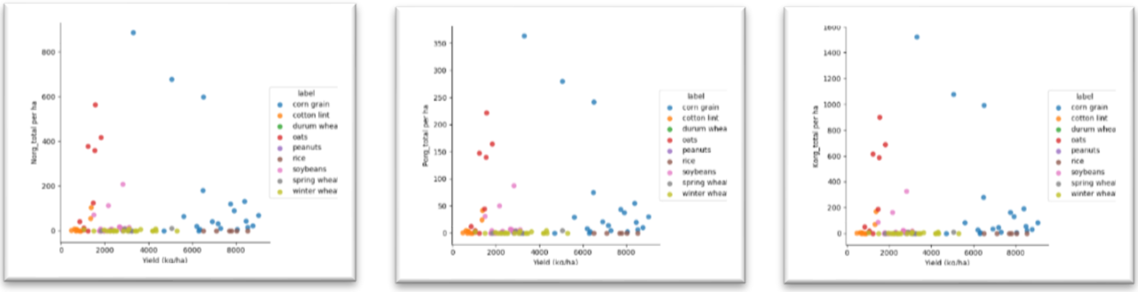


Figure 4-2 (a, b, c): Organic fertilizer inputs (kg per ha) in relation to crop yield (kg per ha).

It can be observed that the scatter plots in Figure 4-2 show very similar patterns (note that the vertical axes have different scales). This can be explained that whereas the NPK ration can be ‘tuned’ for synthetic fertilizers (by applying different fertilizer types), the NPK ratio in organic fertilizers is more fixed (a quantity of animal manure contains a relatively fixed amount of N, P and K). It can also be observed that many crops receive little or no organic fertilizer. Main receivers of organic fertilizers are, oats, corn and to some lesser extent soybeans. A possible reason for this is that these crops are often used for animal feed and may therefore be located closely to sources of organic fertilizers (animal farms). It should be noted that for crops the inputs are extremely high, in particular for corn grown in New York, Pennsylvania, and Wisconsin, and oats grown in Pennsylvania, Michigan and Wisconsin. The figure below also shows this. The majority of crops receive less than 100 kg organic N, with some exceptions.

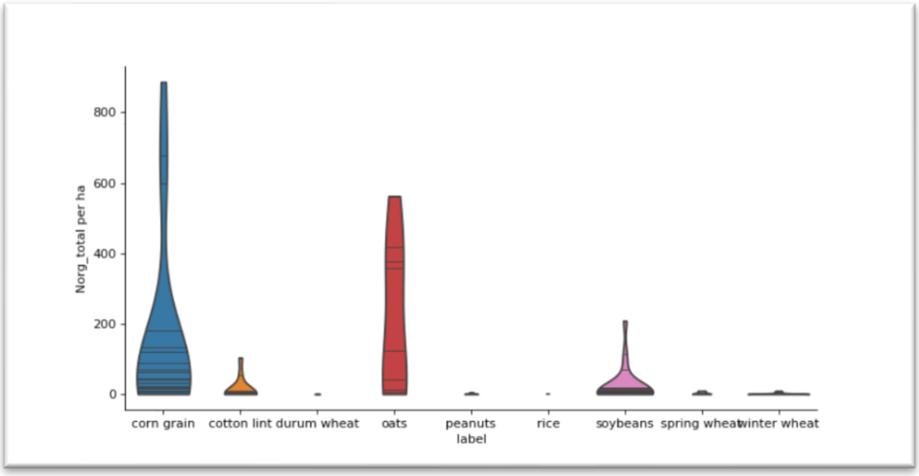


Figure 4-3: Violin plots of Organic Nitrogen application (kg per ha) for different crop types.

4.5.1.3 Water use

Figure 4-4 shows the distributions of water use for the crops in scope (in m3 per ha; 10000 m3/ha = 1 m*ha/ha ~ 3.28 feet*acre per acre).

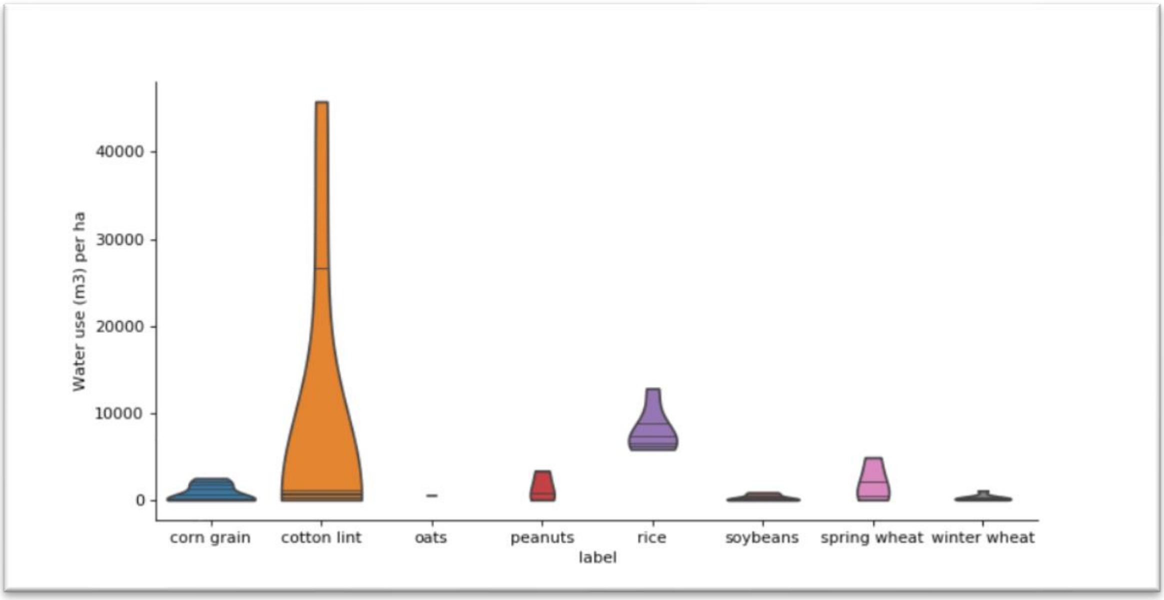


Figure 4-4: Violin plots of Water use (m^3 per ha) for different crops.

It can be seen in the figure that the water use for cotton lint can be extremely high (Cotton AZ = 46 000 m^3/ha, Cotton CA = 26 000 m^3/ha).

In the default Agri-footprint approach we use the Blue water footprint as provided by the Water footprint network (WFN), published in Mekonnen and Hoekstra (2010). The figures below compare the water quantities provided by the LCA commons dataset and the WFN data.

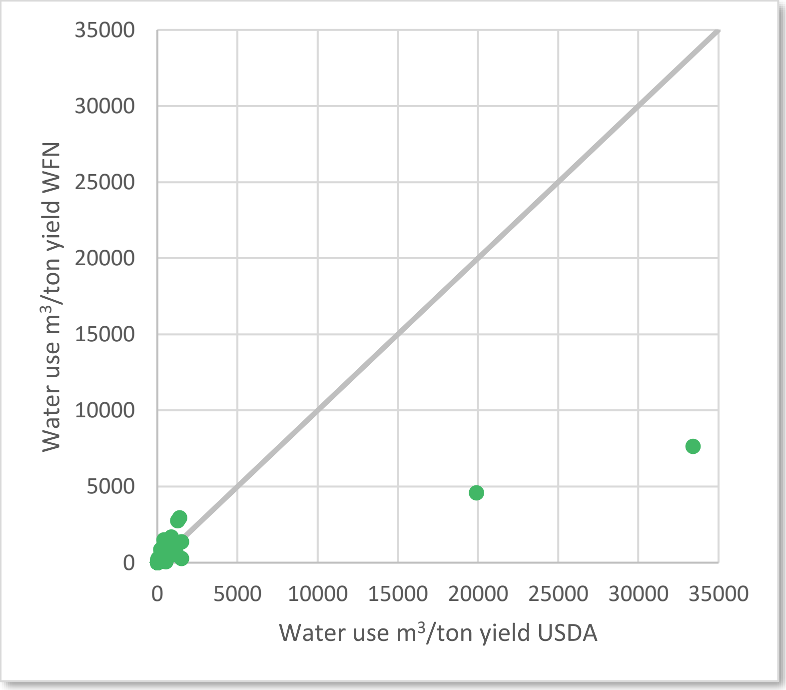


Figure 4-5: Water use (m^3 / ton yield) of the LCA commons dataset to data provided by the Water footprint network

As can be seen in Figure 4-5 (and in more detail in Figure 4-6), the water input data of the WFN does not always correlate well with the data from LCA commons, but there is no structural under- or overestimation of water use when the two datasets are combined. Note that the data from the Water Footprint Network are based on data from end of the 90's early 2000's, so may not be representative for the current situation. In addition, the blue water footprint is based on models based on crop needs, whereas the data in the LCA commons dataset are based on survey data, so it is not surprising that the quantities differ between the two datasets.

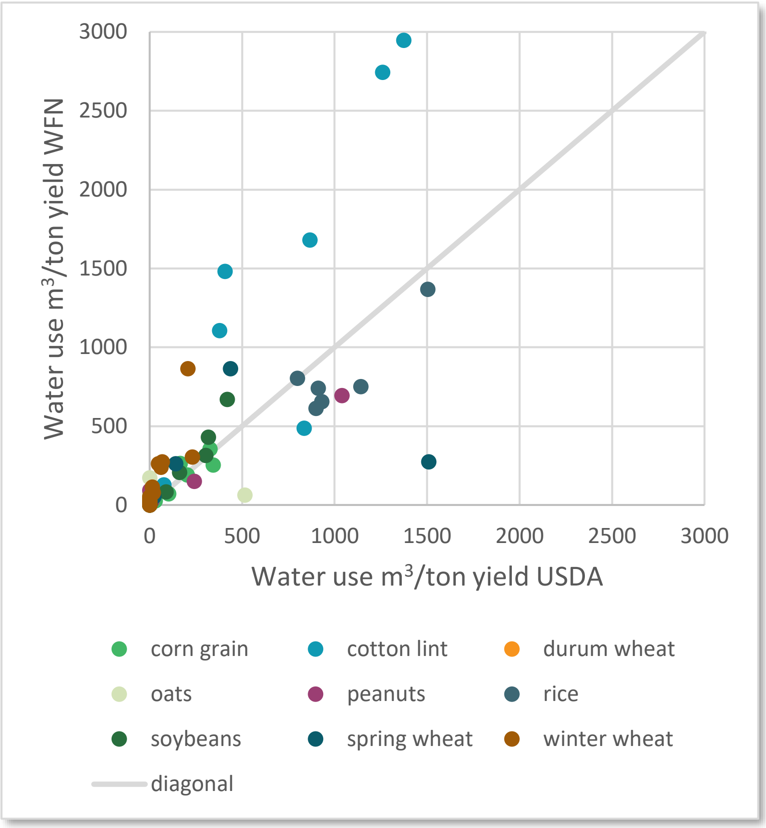


Figure 4-6: Water use (m3 / ton yield) of the LCA commons dataset to data provided by the Water footprint network, outliers removed.

4.5.1.4 Energy inputs

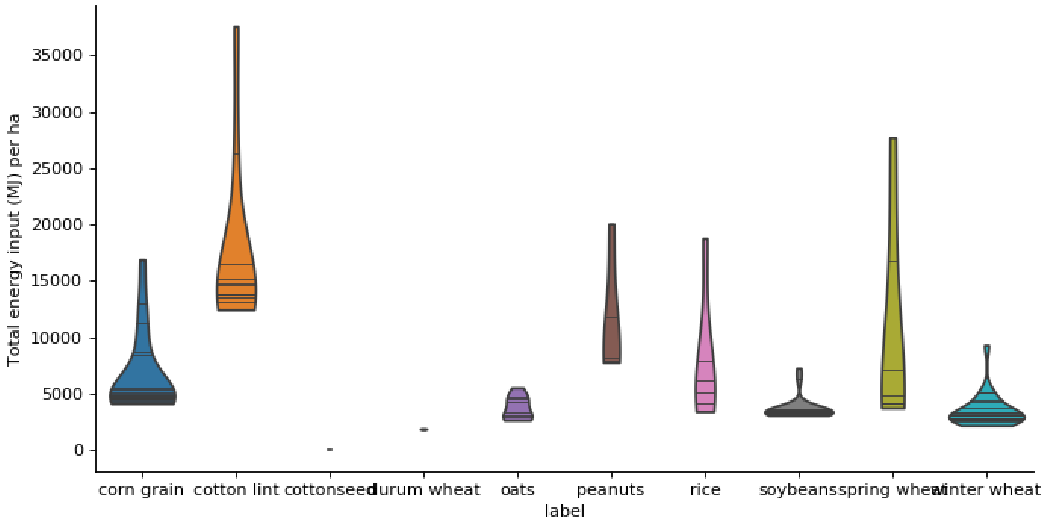


Figure 4-7: Total energy input per Ha.

Again, there are some outliers. Cotton in Arizona and California have a high input of energy. This can be explained by the energy demand for irrigation, as these crops also consume large quantities of water (mainly from underground water supplies, see Figure 4-8a). Also, spring wheat cultivated in Oregon and Indiana have a high input of energy (more specifically electricity), as does corn grown in Colorado and Groundnuts (Peanuts) in Texas.

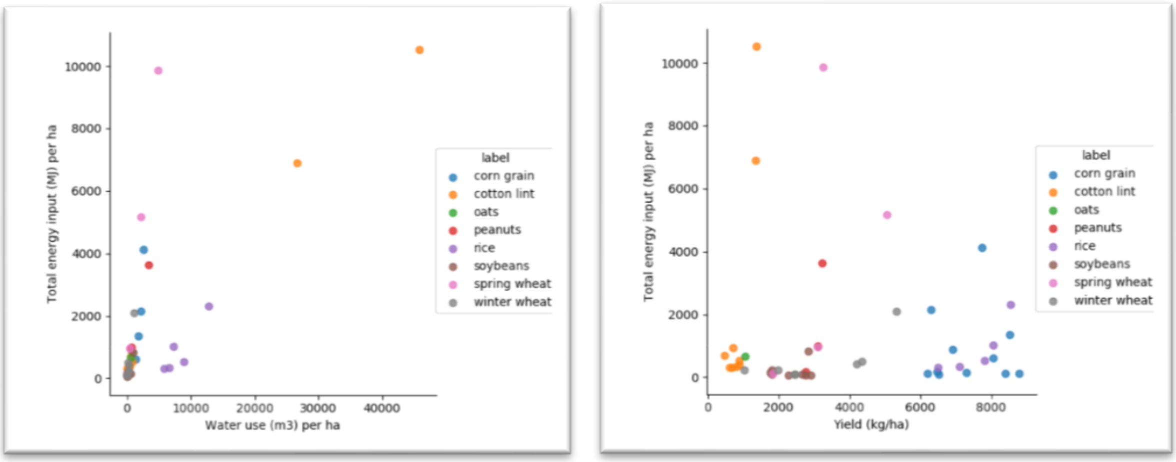


Figure 4-8 (a, b): Total energy input vs. water use and yield respectively.

4.5.2 LCIA results

Some Life Cycle Impact Assessment (LCIA) results (for a selection of indicators from ReCiPe 2016 (H)) are shown in the figures below.

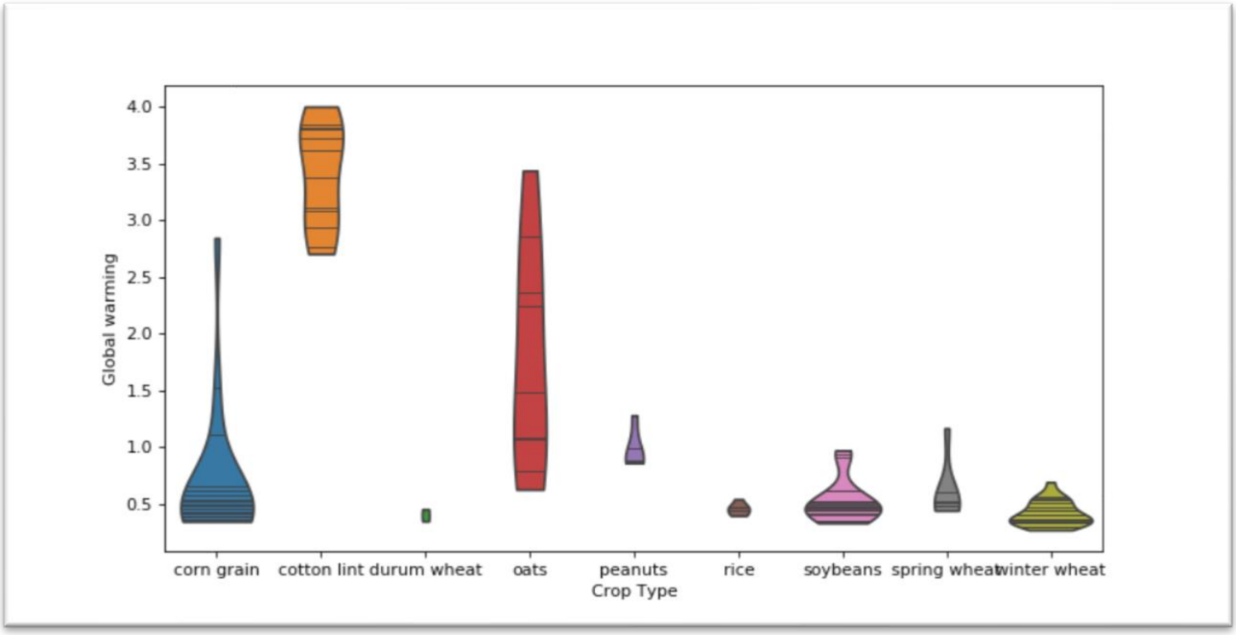


Figure 4-9: Global warming impacts (kg CO_2eq) per kg crop product.

As can be seen in the figure, the impacts per product are generally grouped in a certain range. However, for corn grain there are three outliers that have a higher impact. This has to do with the very high amount of organic manure applied on corn in New York, Pennsylvania, and Wisconsin. For Oats, there is a wider range compared to the other crop products. Again organic manure is the main driver.

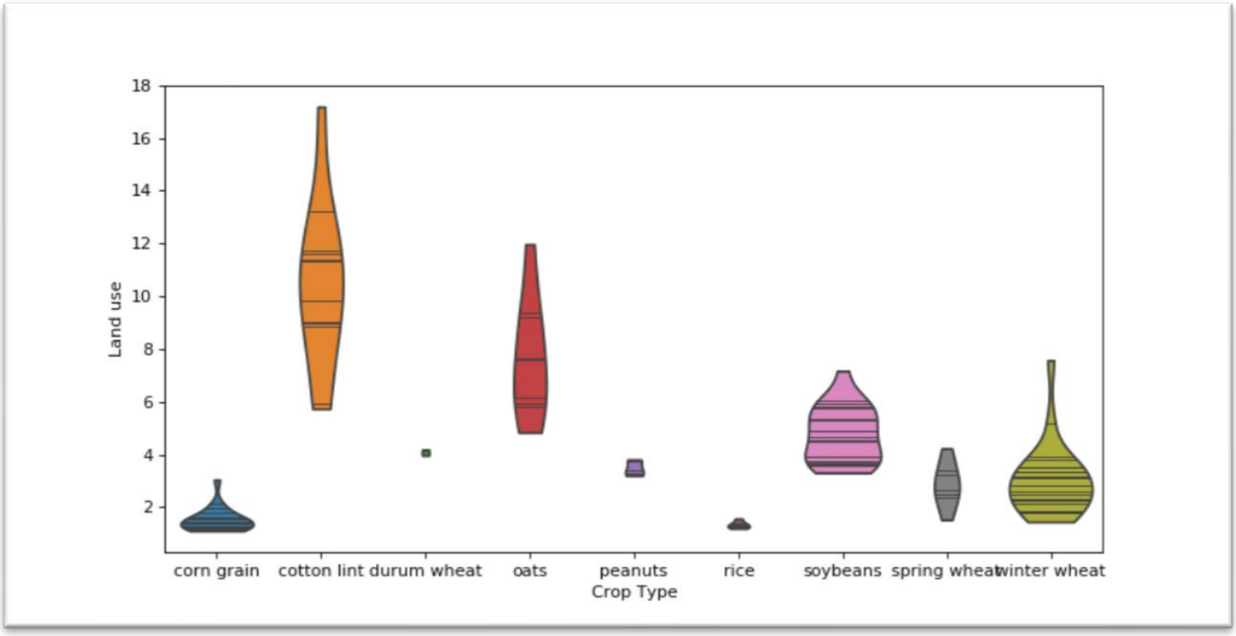


Figure 4-10: Land use (m^2a crop eq) per kg crop product.

The land use per kg is driven by the yield of the crop (more production per ha means less area needed to produce a quantity of crop product). Note that here the Agri-footprint method of calculating land use is used. This means that it is assumed that it is assumed that there is only one crop grown per year. Then the entire year of land occupation is attributed to the crop under study. This method will be improved in future updates to better represent double cropping strategies or longer/shorter growth periods.

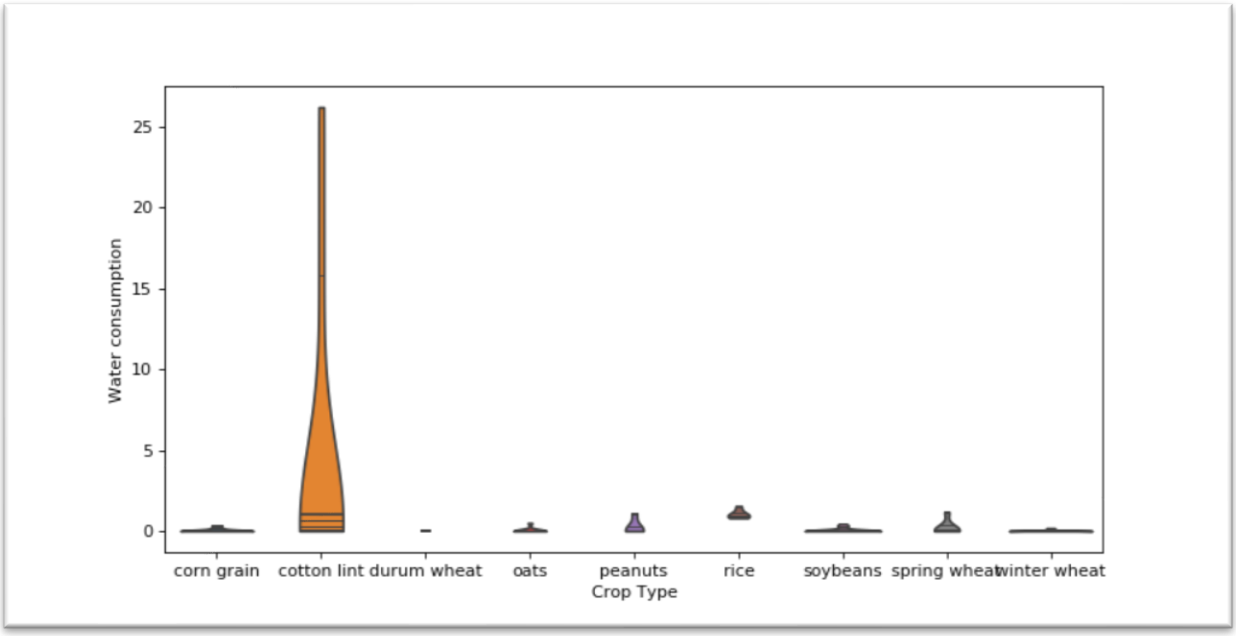


Figure 4-11: Water consumption (m^3) per kg crop product.

The very high water consumption of Cotton in Arizona and California becomes also visible in the impact category water use (see 4.5.1.3).

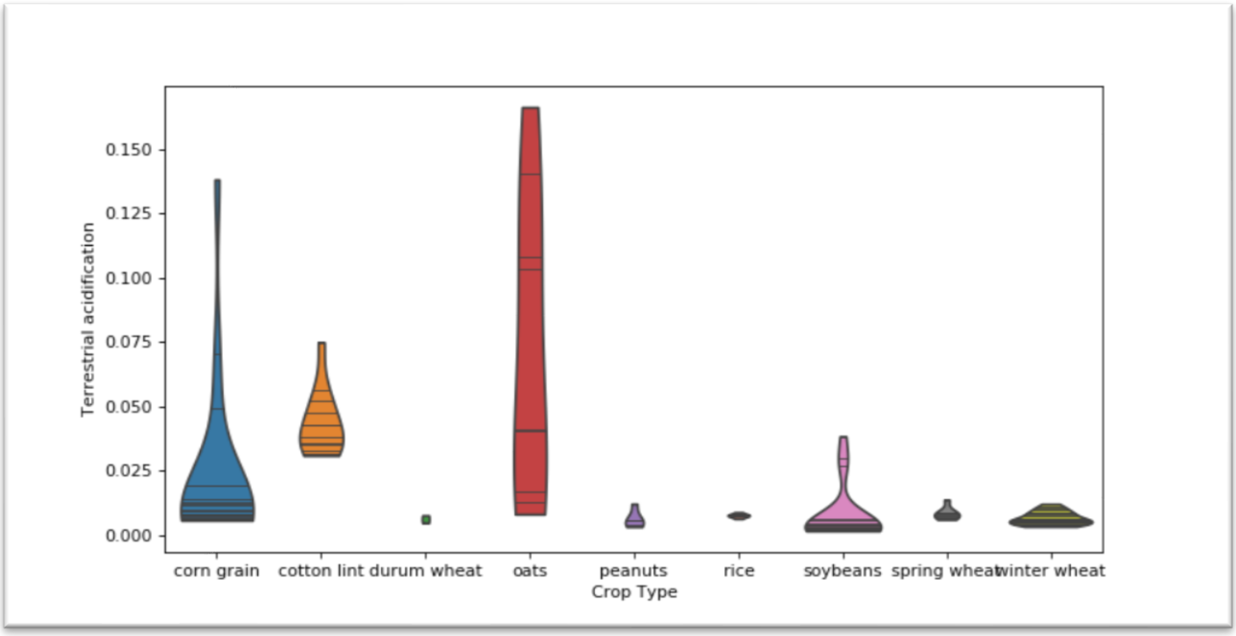


Figure 4-12: Terrestrial acidification (kg SO_2 eq) per kg crop product.

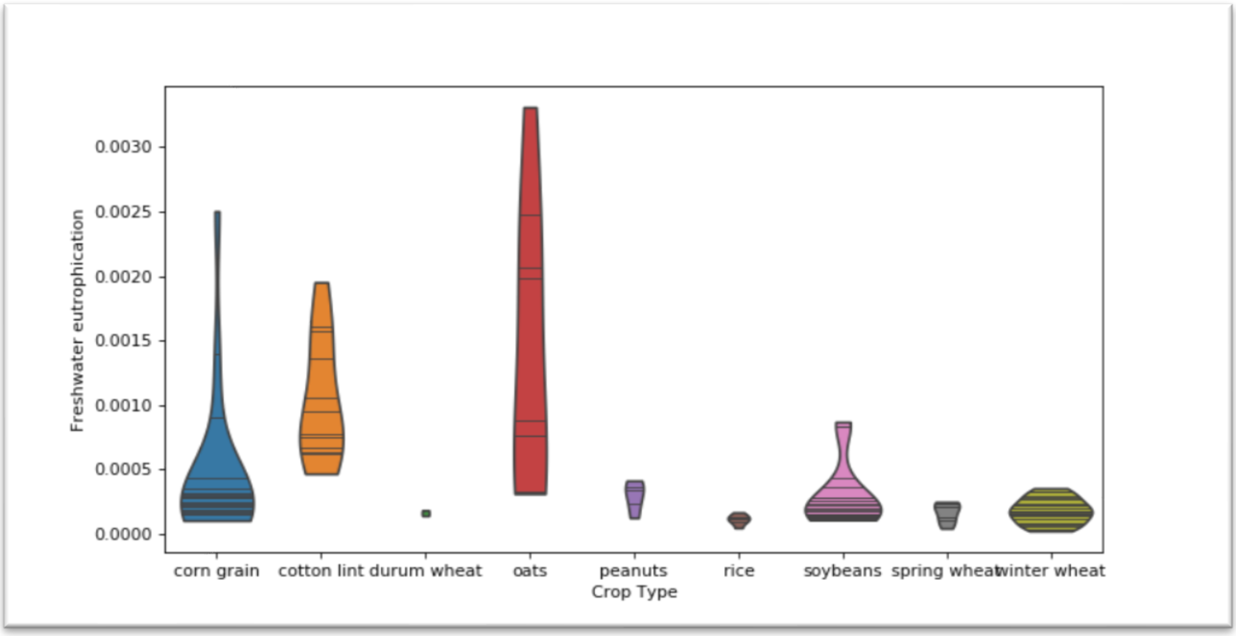


Figure 4-13: Freshwater Eutrophication (kg P eq) per kg crop product.

Terrestrial acidification impacts are mainly driven by emissions of Ammonia. Freshwater Eutrophication impacts are driven by Phosphorous emissions. Both Ammonia and Phosphorous are emitted because of manure and synthetic fertilizer application. The outliers in corn grain and oats crops can therefore again be explained by the high application rates of manure in some states (see 4.5.1.2).

5 Processing of crops and animal farm products

5.1 Introduction and reader's guidance

Table 5-1 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. The complete list is included in Appendix B. Appendix C contains the data required for economic allocation for the cultivation and processing of crops.

Table 5-1 Simplified list of processed feed and food products, and the related data source that formed the basis of the inventory.

Crop	Feed products	Food products	Source and original region of data
Animal products	Blood meal spray, dried Fat from animals Fish meal Greaves meal Meat bone meal Milk powder skimmed Milk powder whole	Pig meat Chicken meat Eggs Cream, full Cream, skimmed Food grade fat Milk powder skimmed Milk powder whole Standardized milk full Standardized milk, skimmed	(van Zeist et al., 2012a)
Barley	Barley straw Barley grain Brewer's grains	Barley grain	(van Zeist et al., 2012b)
Broad bean	Broad bean hulls	Broad bean meal	(Broekema & Smale, 2011)
Cassava	Cassava root dried Cassava peels Cassava pomace	Tapioca starch	(Chavalparit & Ongwandee, 2009) (van Zeist et al., 2012c)
Chickpea		Chickpea, canned	(Broekema & Smale, 2011)
Citrus	Citrus pulp dried		(van Zeist et al., 2012c)
Coconut	Coconut copra meal	Coconut oil	(van Zeist et al., 2012d)
Beans, dry		Beans, dry, canned	(Broekema & Smale, 2011)
Fodder beets	Fodder beets cleaned Fodder beets dirty		(Marinussen et al., 2012b)
Lentil		Lentil, canned	(Broekema & Smale, 2011)
Lupine	Lupine Lupine hulls	Lupine meal	(Marinussen et al., 2012c), (Broekema & Smale, 2011)

Crop	Feed products	Food products	Source and original region of data
Maize	Maize feed meal and bran Maize feed meal Maize germ meal expeller Maize germ meal extracted Maize gluten feed, dried Maize gluten feed Maize gluten meal Maize solubles Maize starch Maize	Maize flour Maize starch Maize germ oil	(van Zeist et al., 2012b, 2012e) (Eijk & Koot, 2005) (Bolade, 2009) (Bechtel et al., 1999)
Oat	Oat grain peeled Oat grain Oat husk meal Oat mill feed high grade Oat straw	Oat grain, peeled	(van Zeist et al., 2012b)
Oil palm	Palm kernel expeller Palm kernels Palm oil	Palm oil Palm kernel oil	(van Zeist et al., 2012d)
Pea	Pea Pea, hulls Pea, starch Pea, slurry	Pea, meal Pea, canned Pea, protein-isolate Pea, protein-concentrate Pea, fibres	(Marinussen et al., 2012c), (Broekema & Smale, 2011)
Rapeseed	Rapeseed expeller Rapeseed meal	Rapeseed oil	(van Zeist et al., 2012d) ((S&T)2 Consultants, 2010) (Schneider & Finkbeiner, 2013)
Rice	Rice husk meal Rice husk	White rice Rice without husk Rice bran Brokens Rice protein Rice starch Rice fibre	(Goyal, S. et al. 2012) (Blengini and Busto, 2009) (Roy, P. et al 2007) (Puchongkavarin, H. et al. 2005) (Shih, F. 2003)
Rye	Rye middlings Rye straw Rye grain	Rye flour	(van Zeist et al., 2012b)
Sorghum	Sorghum		(Marinussen et al., 2012a)
Soy	Soybean oil Soybean protein concentrate Soybean expeller Soybean hulls Soybean meal Soybean heat treated	Soybean oil Soybean protein concentrate	(van Zeist et al., 2012d) (Sheehan, Camobrecco, Duffield, Graboski, & Shapouri, 1998)(OTI, 2010)(Schneider & Finkbeiner, 2013)
Sugar beet	Sugar beet molasses Sugar beet pulp, wet Sugar beet pulp, dried Sugar beet fresh	Sugar	(van Zeist et al., 2012f) (Klenk, Landquist, & Ruiz de Imaña, 2012)
Sugar cane	Sugar cane molasses	Sugar	(van Zeist et al., 2012f)
Starch potato	Potato juice Potato pulp pressed fresh + silage Potato pulp pressed Potato pulp, dried	Potato protein Potato starch dried	(van Zeist et al., 2012e)

Crop	Feed products	Food products	Source and original region of data
Sunflower	Sunflower seed dehulled Sunflower seed expelled, dehulled Sunflower seed meal Sunflower seed with hulls	Sunflower oil	(van Zeist et al., 2012d)
Triticale	Triticale		(Marinussen et al., 2012a)
Wheat	Wheat bran Wheat feed meal Wheat germ Wheat gluten feed Wheat gluten meal Wheat grain Wheat starch, dried Wheat straw	Wheat grain Wheat flour	(van Zeist et al., 2012b, 2012e)

5.2 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 waste water, mixed into feed streams, recycled, as soil improver or other waste), and
- The flows is small and fall well below the cut-off of 5%.

5.3 Water use in processing

Some of the original processing LCI's were taken from Feedprint, and were developed for carbon footprinting. Therefore 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 (see Table 5-2).

Table 5-2 Water use for processing per tonne of input

Main Product	Countries	Water use per tonne input		Comment
Barley feed meal high grade, from dry milling, at plant	BE, DE, FR, NL	0.1	m^3	(Nielsen & Nielsen, 2001)
Maize flour, from dry milling, at plant	DE, FR, NL, US	0.1	m^3	(Nielsen & Nielsen, 2001)
Oat grain peeled, from dry milling, at plant	BE, NL	0.1	m^3	(Nielsen & Nielsen, 2001)
White rice, from dry milling, at plant	CN	0.725	m^3	(Nielsen & Nielsen, 2001)
Rice without husks, from dry milling, at plant	CN	0.725	m^3	(Nielsen & Nielsen, 2001)
Rye flour, from dry milling, at plant	BE, DE, NL	0.1	m^3	(Nielsen & Nielsen, 2001)
Wheat flour, from dry milling, at plant	BE, DE, NL	0.1	m^3	(Nielsen & Nielsen, 2001)
Maize, steeped, from receiving and steeping, at plant	DE, FR, NL, US	2.14	m^3	(European Commission, 2006)
Wheat starch, from wet milling, at plant	BE, DE, NL	2.1	m^3	(European Commission, 2006)
Crude coconut oil, from crushing, at plant	ID, IN, PH	0	m^3	Assumed dry coconut oil extraction process (rather than wet), as currently most economic process.
Crude maize germ oil, from germ oil production (pressing), at plant	DE, FR, NL, US	0	m^3	
Crude maize germ oil, from germ oil production (solvent), at plant	DE, FR, NL, US	0.248	m^3	Rapeseed used as proxy
Crude palm kernel oil, from crushing, at plant	ID, MY	0	m^3	For palm kernel processing, no data is found but is assumed to be insignificant by Schmidt (2007).
Crude palm oil, from crude palm oil production, at plant	ID, MY	0.7	m^3	FeedPrint background data report crushing (van Zeist et al., 2012d)
Crude rapeseed oil, from crushing (pressing), at plant	BE, DE, NL	0	m^3	
Crude rapeseed oil, from crushing (solvent), at plant	BE, DE, NL,US	0.248	m^3	(Schneider & Finkbeiner, 2013)
Crude soybean oil, from crushing (pressing), at plant	AR, BR, NL	0	m^3	
Crude soybean oil, from crushing (solvent), at plant	AR, BR, NL	0.250	m^3	(Schneider & Finkbeiner, 2013)
Crude soybean oil, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL	0.250	m^3	(Schneider & Finkbeiner, 2013)
Crude sunflower oil, from crushing (pressing), at plant	AR, CN, UA	0	m^3	
Crude sunflower oil, from crushing (solvent), at plant	AR, CN, UA	0.248	m^3	Rapeseed used as proxy
Fodder beets cleaned, from cleaning, at plant	NL	0	m^3	Assumed that it is cleaned mechanically, as is common practice in NL
Cassava root dried, from tapioca processing, at plant	TH	0	m^3	
Potato starch dried, from wet milling, at plant	DE, NL	1.1	m^3	(European Commission, 2006)
Sugar, from sugar beet, from sugar production, at plant	DE, NL	0.27	m^3	

Main Product	Countries	Water use per tonne input		Comment
Sugar, from sugar cane, from sugar production, at plant	AU, BR, IN, PK, SD, US	0.125	m^3	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.
Tapioca starch, from processing, at plant (with and without use of co-products)	TH	0.428	m^3	(Chavalparit & Ongwandee, 2009)
Broad bean, meal	NL	0	m^3	(Broekema & Smale, 2011)
Lupine, meal	NL	0	m^3	(Broekema & Smale, 2011)
Pea, meal	EU	0	m^3	(Broekema & Smale, 2011)
Pea, protein-concentrate	EU	0	m^3	(Broekema & Smale, 2011)
Pea, protein-isolate	EU	6.262	m^3	(Broekema & Smale, 2011)
Pea, canned	EU	1.944	m^3	(Broekema & Smale, 2011)
Beans, dry, canned	NL	1.944	m^3	(Broekema & Smale, 2011)
Lentil, canned	NL	2.940	m^3	(Broekema & Smale, 2011)
Chickpea, canned	NL	1.718	m^3	(Broekema & Smale, 2011)
Pea, fibres	EU	0	m^3	

5.4 Emission of Hexane in solvent crushing of oil crops

The original processing LCIs of feedprint (that formed the basis of Agri-footprint 1.0) contained an input of hexane (to make up for processing losses), but not a hexane emission. It was assumed that all hexane that was lost during the processing is emitted to air.

Table 5-3: Hexane emissions from solvent crushing

Main product	Countries	Emission of hexane to air (kg / tonne oil crop input)
Crude maize germ oil, from germ oil production (solvent), at plant	DE, FR, NL, US	1.01
Crude rapeseed oil, from crushing (solvent), at plant	BE, DE, NL, FR, PL	0.6
Crude rapeseed oil, from crushing (solvent), at plant	US	0.85
Crude soybean oil, from crushing (solvent), at plant	AR, BR,	0.8
Crude soybean oil, from crushing (solvent), at plant	NL, DE, ES	0.6
Crude soybean oil, from crushing (solvent), at plant	US	0.8
Crude soybean oil, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL	0.8
Crude sunflower oil, from crushing (solvent), at plant	AR, CN, UA	1
Crude rice bran oil, from rice bran oil production, at plant	CN	0.41

5.5 Combustion of bagasse in sugar cane processing plants

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 5-4.

Table 5-4: 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

5.6 Cassava root processing in Thailand with and without use of co-products

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 *(see Table 5-5)*
- Tapioca starch, from processing without use of co-products *(see Table 5-6).*

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 m^3 of waste water is generated to produce 1 tonne of tapioca starch output. This is identical to 454 kg of waste water per tonne of cassava root input. In Table 5-5, the amount of peels are subtracted (454 kg – 90 kg) of the waste water because peels are used as feed and do not end up in the waste water. In Table 5-6, the pomace will end up in the waste water so the waste water amount increased (454 kg + 150 kg).

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

Table 5-5: Inventory of Tapioca starch, from processing with use of co-products (not including energy and Sulphur)

		DM (%)	Output (kg fresh out / ton fresh in)	Output (kg DM out / ton DM in)	Economic Allocation Fractions[a] (%)	Gross Energy (MJ/kg)
Input	Cassava root, fresh	32	1000	320	n/a	14.68
Input	Drinking water	0	428	0	n/a	n/a
Output	Tapioca starch	88.0	240	211	95	15.4
Output	Cassava peels, fresh	28.2[b]	90	25	2.5	15.7
Output	Cassava pomace (fibrous residue), fresh	13.1[b]	150[c]	20	2.5	17.3
Output	Waste water	0	364	64	n/a	n/a

a; Prices of peels and pomace were not found. The economic allocation fraction cassava starch is assumed to be the same as sugar cane. The remaining fraction is divided over the co-products.
b; Based on (Feedipedia, 2014).
c; Feedipedia mentions that pomace output can be up to 17% of the tuber. Here 15% is assumed.

Table 5-6: Inventory of Tapioca starch, from processing without use of co-products (not including energy and Sulphur)

		DM (%)	Output (kg fresh out / ton fresh in)	Output (kg DM out / ton DM in)	Economic Allocation Fractions (%)	Gross Energy (MJ/kg)
Input	Cassava root, fresh	32	1000	320	n/a	14.68

Input	Drinking water	0	428	0	n/a	n/a
Output	Tapioca starch	88	240	211	100	15.4
Output	Waste water	0	604	109	n/a	n/a

5.7 Vegetable 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 5-7: 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)	(Schneider & Finkbeiner, 2013)	(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 5-8: Average process in and outputs of oil refining of maize germ oil, rice bran oil, coconut oil, palm kernel 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

5.7.1 Allocation

Table 5-9 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 5-10.

Table 5-9: 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	8.03	(Schneider & Finkbeiner, 2013)
Value soap stock	€/kg	0.200	0.350	-	
Value fatty acid distillate	€/kg	-	-	6.32	

Table 5-10: 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	

5.8 Crushing of oil seeds

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). See Table 5-11 and Table 5-12.

Table 5-11: Crushing of soybeans in EU countries (NL, DE, ES) (Schneider & Finkbeiner, 2013), and US (OTI, 2010; Sheehan et al., 1998). DM: Dry Matter; GE: Gross Energy

		Quantity	Comment	Quantity	Comment
Products					
Crude soybean oil, from crushing (solvent), at plant	kg	192.3	DM: 1000 g/kg GE: 39.13 MJ/kg	190	DM: 1000 g/kg GE: 39.13 MJ/kg
Soybean hulls, from crushing (solvent), at plant	kg	74.5	DM: 880 g/kg GE: 15.96 MJ/kg	74	DM: 880 g/kg GE: 15.96 MJ/kg
Soybean meal, from crushing (solvent), at plant	kg	710.1	DM: 880 g/kg GE: 17.36 MJ/kg	706	DM: 880 g/kg GE: 17.36 MJ/kg
Soybean lecithin, from crushing (solvent), at plant	kg	3.8	-	-	-
Materials / fuels					
Hexane, at plant	kg	0.6	-	0.8	-
Country specific crop mix		See database		See database	
Country specific transport mix		See database		See database	
Drinking water, water purification treatment, production mix, at plant, from groundwater	ton	0.25	-	0.25	-
White mineral oil, at plant	kg	0.02	-	-	-
Electricity/ heat					
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	103.8	-	200	-
Process steam from natural gas, heat plant, consumption mix, at plant	MJ	828.1	-	1200	-
Emissions to air					
Hexane	kg	0.6	-	0.8	-
Hydrogen sulfide	kg	0.004	-	-	-
Waste and emissions to treatment					
Landfill of biodegradable waste	kg	19.3	-	30	-
Waste water – untreated, organic contaminated	kg	250	-	250	-

Table 5-12: Crushing of rapeseed in EU countries (NL, DE, BE, FR, PL) (Schneider & Finkbeiner, 2013) and US ((S&T)2 Consultants, 2010) DM: Dry Matter; GE: Gross Energy.

		Quantity	Comment	Quantity	Comment
Products					
Rapeseed meal, from crushing (solvent), at plant	kg	574.4	DM: 885 g/kg GE: 17.53 MJ/kg	518	DM: 885 g/kg GE: 17.53 MJ/kg
Crude rapeseed oil, from crushing (solvent), at plant	kg	413.2	DM: 1000 g/kg GE: 39.13 MJ/kg	428	DM: 1000 g/kg GE: 39.13 MJ/kg
Materials / fuels					
Hexane, at plant	kg	0.6	-	0.85	-
Country specific crop mix		See database		See database	
Country specific transport mix		See database		See database	
Drinking water, water purification treatment, production mix, at plant, from groundwater	ton	0.248	-	0.248	-
Electricity/ heat					
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	148.8	-	176.4	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	MJ	807.6	-	1000	-
Emissions to air					
Hexane	kg	0.6	-	0.85	-
Hydrogen sulfide	kg	0.062	-	-	-
Water	kg	17	-	17	-
Waste and emissions to treatment					
Landfill of biodegradable waste	kg	12.4	-	12.4	-
Waste water - untreated, organic contaminated	kg	248	-	248	-

5.9 Dry milling of maize

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). See Table 5-13.

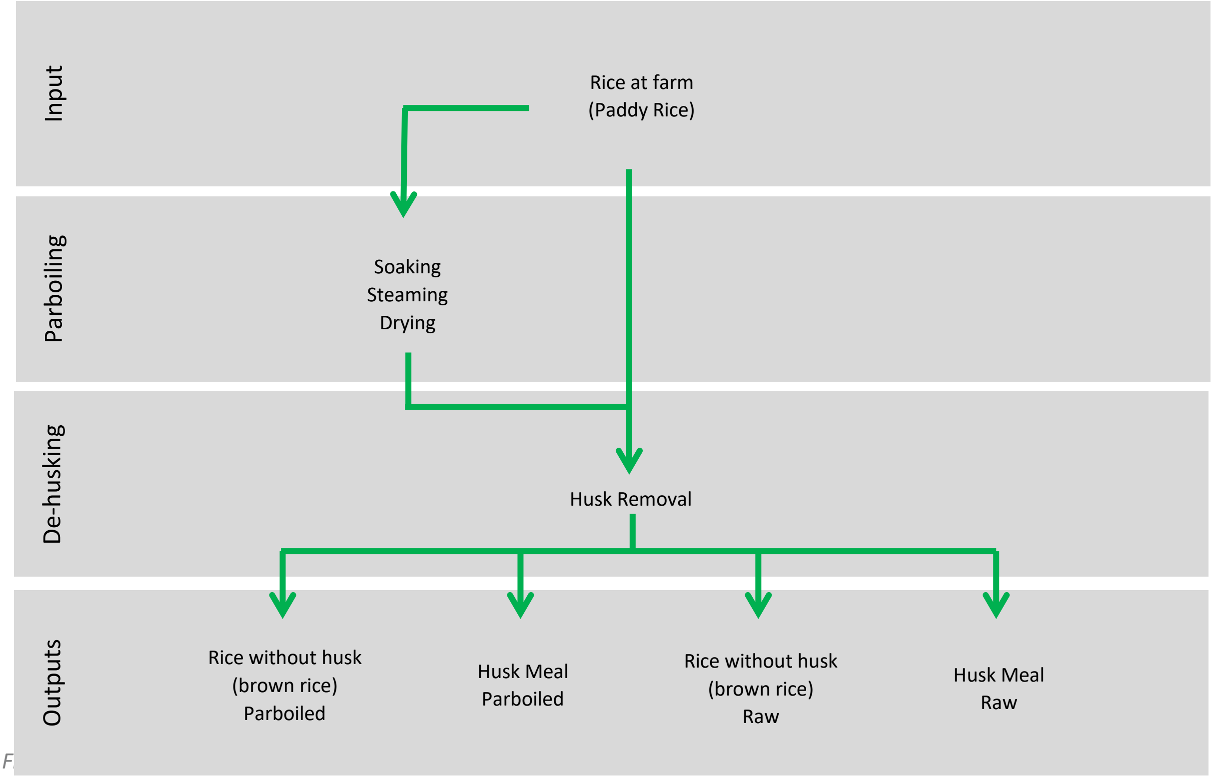
Table 5-13: Dry milling of maize in EU countries (NL, FR, DE, IT, PL) (Bolade, 2009)(Eijk & Koot, 2005) DM: Dry Matter; GE: Gross Energy

		Quantity	Comment
Products			
Maize flour, from dry milling, at plant/DE Economic	kg	595	DM: 884 g/kg GE: 15.5 MJ/kg
Maize middlings, from dry milling, at plant/DE Economic	kg	405	DM: 873 g/kg GE: 14.7 MJ/kg
Materials / fuels			
Country specific crop mix		See database	-
Country specific transport mix		See database	-
Drinking water, water purification treatment, production mix, at plant, from groundwater	ton	0.1	-
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	290	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	MJ	174	-
Waste and emissions to treatment			
Waste water - untreated, organic contaminated	kg	100	-

5.10Rice post-harvest processing

5.10.1Rice husk meal & brown rice dry milling

This process describes the production of rice without husks and rice husks from a rice dry milling process in China (Figure 5-1). Rice without husks is also referred to as brown rice, while the 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 husk are removed by friction leaving the paddy intact.



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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 publically 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.

Table 5-14: Rice husk meal and brown rice dry milling in Asian countries, based on China, per Tonne of paddy rice.DM = Dry matter; GE= Gross Energy. (Blengini & Busto, 2009; Goyal et al., 2012; IRRI, 2015b; Roy et al., 2007)

		Quantity	Comment
Products			
Rice husk meal, from dry milling, at plant/CN	kg	200	DM: 910 g/kg GE: 14.7 MJ/kg
Rice without husks, from dry milling, at plant/CN	kg	800	DM: 870 g/kg GE: 16.1 MJ/kg
Materials / fuels			
Drinking water, water purification treatment, production mix, at plant, from groundwater	ton	1.2	For Parboiling
Rice, at farm/CN	ton	1	
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	935.3	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	MJ	87.9	-
Waste and emissions to treatment			
Waste water - untreated, organic contaminated	kg	1200	-

5.10.2Rice dry milling

This process describes the production of white rice, rice husks, rice bran and rice brokens from a rice dry milling process in China (Figure 5-2). 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 husk 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 publically reported data for milling (Blengini & Busto, 2009; Roy & et al., 2007).

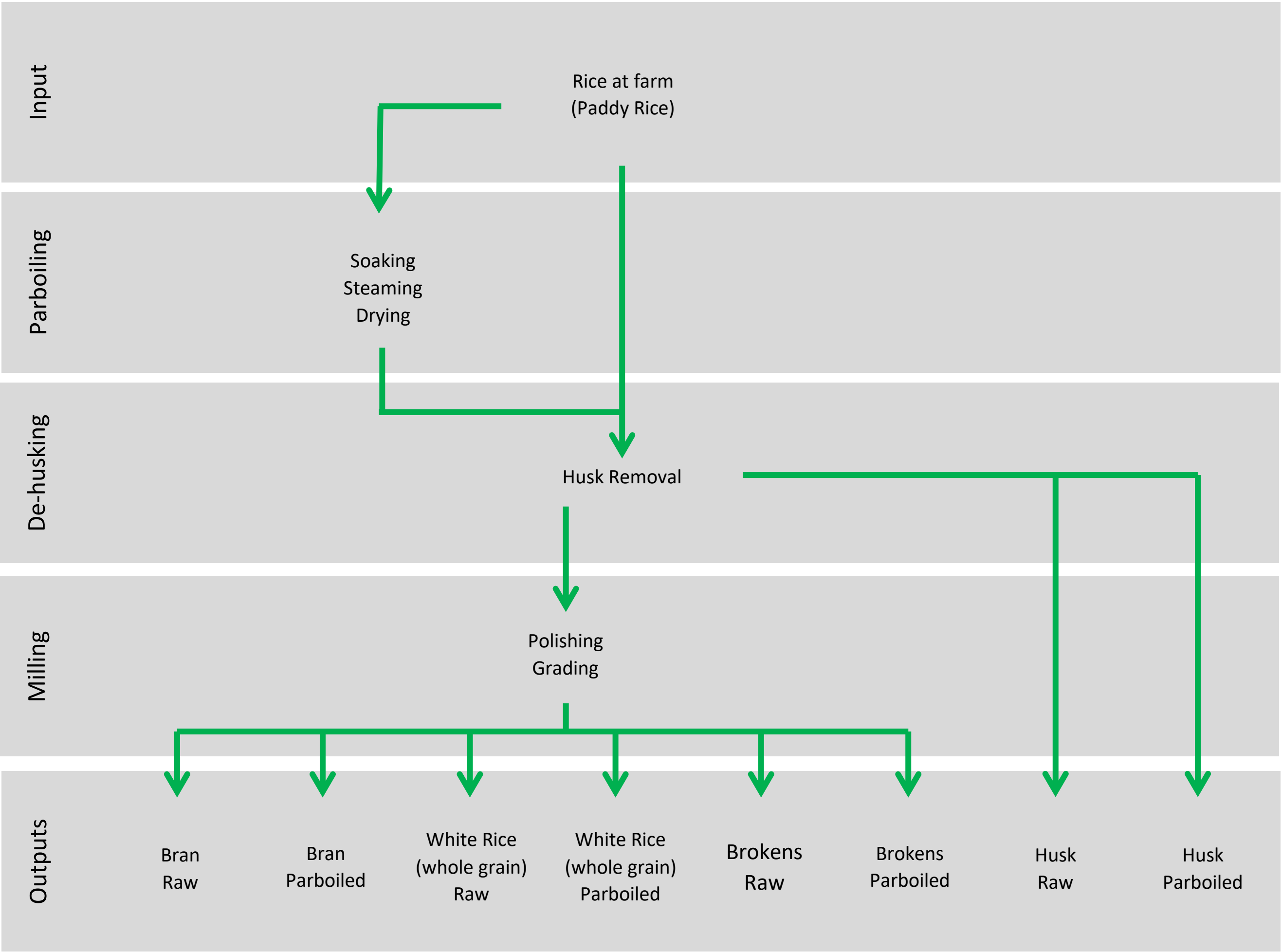
Input
Rice at farm
(Paddy Rice)
Parboiling
Soaking
Steaming
Drying
De-husking
Husk Removal
Milling
Polishing
Grading
Outputs
Bran
Raw
Bran
Parboiled
White Rice
(whole grain)
Raw
White Rice
(whole grain)
Parboiled
Brokens
Raw
Brokens
Parboiled
Husk
Raw
Husk
Parboiled

Table 5-15 Rice dry milling in China, per tonne of paddy rice. (Blengini & Busto, 2009; Goyal et al., 2012; IRRI, 2015b; Roy et al., 2007)

		Quantity	Comment
Products			
Rice bran, from dry milling, at plant/CN Mass	kg	100	DM: 910 g/kg GE: 14.7 MJ/kg
Rice husk, from dry milling, at plant/CN Mass	kg	200	DM: 910 g/kg GE: 14.7 MJ/kg
White rice, from dry milling, at plant/CN Mass	kg	644	DM: 870 g/kg GE: 16.1 MJ/kg
Rice Brokens, from dry milling, at plant/CN Mass	kg	56	DM: 870 g/kg GE: 16.1 MJ/kg
Materials / fuels			
Drinking water, water purification treatment, production mix, at plant, from groundwater	ton	0.6	Parboiling
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	782.3	Consumption Mix (50% parboiled + 50% raw)
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	MJ	43.9	
Waste and emissions to treatment			
Waste water - untreated, organic contaminated	kg	600	Consumption Mix (50% parboiled + 50% raw)

5.10.3 Rice protein extraction

This process describes the extraction of rice protein, starch and rice fibre by the alkaline method (Figure 5-3). The process starts with a rice kernel which can be either husks, white or brown rice or bran. The most common kernels are the bran as it has the highest protein content (13%) followed by the white and brown rice (7%).

The alkaline method for protein extraction typically consists of steeping, decanting, washing the kernel several times with water and Sodium Hydroxide. The resulting cake is passed through a vibration sieve to separate the fibre. Afterwards, a solution is prepared, in order to neutralize the cake using Sulphuric Acid, and then washed and decanted. The cake is centrifuged two times and dried. From this process the rice starch is obtained. The starch follows a separation and recovery process to isolate the protein.

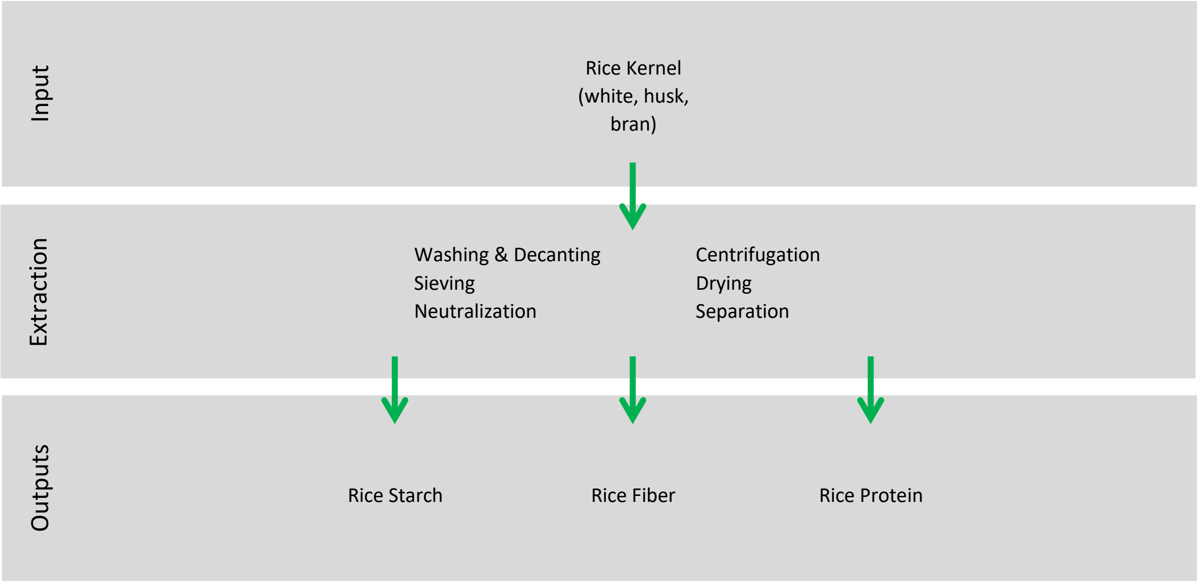

Figure 5-3: Diagram summarizing the process of extraction of rice protein, starch and rice fibre by the alkaline method.

Publically available literature for this process is limited, theoretical data was adapted and serverd as a starting point to calculated from data available from different sources (Puchongkavarin, et al. 2005; Shih, 2003).

Table 5-16 Rice protein extraction (Puchongkavarin, et al. 2005; Shih, 2003)

Products			
Rice protein, protein extraction, at plant/GLO Mass	ton	1	DM: 910 g/kg GE: 14.7 MJ/kg
Rice starch, protein extraction, at plant/GLO Mass	ton	11.1	DM: 910 g/kg GE: 14.7 MJ/kg
Rice fibre, protein extraction, at plant/GLO Mass	ton	1.7	DM: 870 g/kg GE: 16.1 MJ/kg
Materials / fuels			
White rice, from dry milling, at plant/CN Mass		See database	-
Global transport mix (CN to NL – proxy)		See database	-
Drinking water, water purification treatment, production mix, at plant, from groundwater	ton	239.4	-
Sodium hydroxide (50% NaOH), production mix/RER Mass	ton	0.11	-
Sulfuric acid (98% H2SO4), at plant/RER Mass	ton	1.41	-
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	278	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	MJ	1580	-
Waste and emissions to treatment			
Waste water - untreated, organic contaminated	kg	239.44	-

5.11Sugar production, 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 quite 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.

Table 5-17: Sugar production from sugar beet in EU countries (DE, FR, PL) (Klenk et al., 2012) DM: Dry Matter; GE: Gross Energy.

		Quantity	Comment
Products			
Lime fertilizer, from sugar production, at plant/FR Economic	kg	27	DM: 500 g/kg GE: 0 MJ/kg
Sugar, from sugar beet, from sugar production, at plant/FR Economic	kg	128	DM: 1000 g/kg GE: 17.36 MJ/kg
Sugar beet pulp, wet, from sugar production, at plant/FR Economic	kg	385	DM: 218 g/kg GE: 3.4 MJ/kg
Sugar beet molasses, from sugar production, at plant/FR Economic	kg	40	DM: 723 g/kg GE: 12.18 MJ/kg
Avoided products			
Electricity mix, AC, consumption mix, at consumer, < 1kV FR	kWh	3.76	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	kWh	0.376	-
Materials/ fuels			
Country specific crop mix		See database	
Country specific transport mix		See database	
Crushed stone 16/32, open pit mining, production mix, at plant, undried RER	kg	15.36	-
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV	kWh	9.50	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	kWh	194.82	-
Waste and emissions to treatment			
Waste water - untreated, organic contaminated	kg	100	-

5.12Dairy products

5.12.1Cheese and liquid whey production

Cheese is produced from standardized 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. KWA Bedrijfsadviseurs was approached to supply a complete dataset from Dutch dairy industry with mass balances and energy use. Cheese production was modelled after information provided by KWA Bedrijfsadviseurs in 2011. The composition of the products was based on (van Zeist et al., 2012a), see Table 5-18.

Table 5-18: Cheese and liquid whey production in the Netherlands. DM: Dry Matter; GE: Gross Energy

		Quantity	Comment
Products			
Cheese, from cheese production, at plant/NL Economic	kg	128	DM: 562.5 g/kg GE: 15,3 MJ/kg
Liquid whey, from cheese production, at plant/NL Economic	kg	868	DM: 49.5 g/kg GE: 0,8 MJ/kg
Materials/ fuels			
Standardized milk, skimmed, from processing, at plant/NL Economic	kg	1000	-
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL	MJ	56.0	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S	MJ	109.0	-

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 after information provided by KWA Bedrijfsadviseurs in 2011. The composition of the products was based on van Zeist et al. (2012a), see Table 5-19.

Table 5-19: Drying of liquid whey. DM: Dry Matter; GE: Gross Energy

Products			
Whey powder, from drying, at plant/NL Economic	kg	53	DM: 950 g/kg GE: 15,3 MJ/kg
Materials/ fuels			
Liquid whey, from cheese production, at plant/NL Economic	kg	1000	-
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, <1kV	MJ	45	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27	MJ	325	-

5.13Processing of pulses

5.13.1 Crop/country mix

Broekema & Smale (2011) have performed an LCA on the processing of pulses in the Netherlands, which forms the basis for the processing of pulses in the Agri-footprint database. From this study, the gate-to-gate data were used for the processing, as well as the selection of crop/country combination that is processed in the Netherlands. An equal share is attributed to each of the crop/country combinations based on expert judgement (Broekema & Smale, 2011). An exception to this procedure has been made for dry peas. For this crop, the shares of the different crop/countries of the European mix have been determined using production and import data for the EU from the Eurostat database, see Table 5-20. Since cultivation data was available for France and Germany, the percentages derived from the Eurostat database are reweighted to these two countries.

Table 5-20: Top 5 producers of dry peas for the European market according to Eurostat data, and the percentage used in Agri-footprint database.

Countries	Percentage of the European production (%)	Reweighted percentage used in Agri-footprint database (%)
France	38	84
Spain	11	-
Germany	9	16
United Kingdom	7	-
Canada	5	-

5.13.2 Inputs and outputs of processing

Table 5-21 and Table 5-22 show the inputs and outputs of the processing of pulses based on Broekema & Smale (2011). The only input and output data not found in Broekema & Smale (2011) were the water input and the waste water output, which have been calculated using dry matter and water balances. Furthermore, the production of pea fibres from pea hulls was modeled using a proxy from the dry milling of dried wheat grain.

*Table 5-21: Input data for main processes of pulses. * The input for pea fibres is 1000 kg of pea hulls instead of 1000 kg of pulses.*

Main process	Pulses (kg)	DM content (%)	Gas (m^3)	Oil (l)	Electricity (kWh)	Steel (kg)	Water (l)
Beans, dry, Canned	349	84	57	0	91	165	679
Chickpea, Canned	379	86	57	0	91	165	651
Lentil, Canned	259	88	57	0	91	165	761
Pea, Canned	349	84	57	0	91	165	679
Broad bean, Meal	1000	84	0	11.5	209	0	0
Lupine, Meal	1000	91	0	11.5	278	0	0
Pea, Meal	1000	84	0	11.5	209	0	0
Pea, Protein-concentrate	1000	84	0	11.5	209	0	0
Pea, Protein-isolate	1000	84	116	40	278	0	6262
Pea, Fibre	1000*	90	5.5	0	80.5	0	0

Table 5-22: Output data for main processes of pulses.

Main process	Pulses Canned (kg)	Protein -isolate (kg)	Protein-concentrate (kg)	Protein (kg)	Meal (kg)	Hulls (kg)	Fibres (kg)	Slurry (kg)	Waste water (kg)
Beans, dry, Canned	1000	-	-	-	-	-	-	-	-
Chickpea, Canned	1000	-	-	-	-	-	-	-	-
Lentil, Canned	1000	-	-	-	-	-	-	-	-
Pea, Canned	1000	-	-	-	-	-	-	-	-
Broad bean, Meal	-	-	-	-	620	280	-	-	64
Lupine, Meal	-	-	-	-	731	234	-	-	5
Pea, Meal	-	-	-	-	709	187	-	-	64
Pea, Protein-concentrate	-	-	437	437	-	49	-	-	76
Pea, Protein-isolate	-	169	-	422	-	112	-	6559	-
Pea, Fibre	-	-	-	-	-	-	1000	-	-

5.13.3 Allocation

Table 5-23 shows the dry matter (DM) content, prices and gross energy (GE) content used for allocation purposes for all pulses outputs.

*Table 5-23: Key parameters for mass, energy and economic allocation. *These are not the actual prices, but the ratio of prices of lupine meal and lupine hulls (expert judgement from industry (Broekema & Smale, 2011)**The pea starch from protein-isolate production is of high quality and used in food production, while the pea starch from protein-concentrate is of lower quality and used in animal feed production.*

Output	DM content (g/kg)	GE content (MJ/kg)	Price (€/ton)
Broad bean, meal	900	18.0	550
Broad bean, hulls	900	9.2	129
Lupine, meal	920	18.9	2.5*
Lupine, hulls	900	10.6	0.75*
Pea, meal	900	15.1	450
Pea, hulls (50% food quality)	900	9.0	265
Pea, protein-concentrate	910	16.3	1800
Pea, starch (from protein-isolate)	910	16.0	600**
Pea, starch (from protein-concentrate)	910	16.0	125**
Pea, protein-isolate	940	17.0	2800
Pea, slurry	30	0.3	0
Beans, dry, canned	270	na	na
Chickpea, canned	300	na	na
Lentil, canned	210	na	na
Pea, canned	270	na	na

5.14 Broad bean (EU 28+3)

Largest producers of broad beans in Europe are France (48%), United Kingdom (18%), Italy (13%) and Germany (10%). These four countries are considered for the European broad bean mix, covering 88% of the European production mix. Most important parameters are mentioned in the table below. Yields are derived from FAO stat and starting material (FAOSTAT, 2000) and NPK fertilizer use from fifth edition on fertilizer use by crop from FAO (FAO, 2006).

Country	Production mix (2010-2014)	Model mix	Yield (kg/ha) (2010-2014)	Starting material (kg/ha)	N kg/ha	P kg/ha	K Kg/ha
France	47.65%	54.26%	37,648	100	150	85	180
United Kingdom	17.80%	20.27%	41,316	218	5	30	35
Italy	12.80%	14.58%	19,294	231	30	40	40
Germany	9.56%	10.89%	37,291	200	25	30	45
Total	87.81%	100.00%					

Pesticide use during cultivation of the crop of the four countries could be found for France, Germany and Italy. Pesticide use for the UK will be based on French pesticide use. Overview of the pesticide use can be found in the tables below.

Table 5-24: Pesticide use for Italian broad bean cultivation, based on (Brau, Coghe, & Farigu, 1997)

Commercial product	Active substance	Concentration	Unit	Application	Unit2	# applications	Total (kg/ha)
Pursuit ST	Imazethapyr	0.2287	%	2.5	L	1	0.57175
Igran L	Terbutryn	0.5	Kg/l	1.5	L	1	0.75
Whip S	Fenoxaprop-p-ethyl	0.093	%	1.5	L	1	0.1395
Fusilade N 13	Fluazifop-p-butyl	0.13	%	1.75	L	1	0.2275
Illoxan	diclofop-methyl	0.347	%	2.75	L	1	0.95425
Fervinal, Grasidim	Sethoxydim	0.95	%	1.5	L	1	1.425

Table 5-25: Pesticide use for German broad bean cultivation, based on (Bischoff et al., 2015)

Commercial product	Active substance	Concentration	Unit	Application	Unit2	# applications	Total (kg/ha)
Stomp Aqua	Pendimethalin	400	g/l	5.7	L	1	2.28
Bundur	Aclonifen	600	g/l	3.75	L	1	2.25
Centium 36 CS	Clomazone	360	g/l	0.45	L	1	0.162
Boxer	Prosulfocarb	800	g/l	7.5	L	1	6
Basagran	Bentazone	480	g/l	1.8	L	1	0.864

5.14.1 Groundnut meal, from crushing, at plant

Groundnut processing for five countries are considered, which are: Argentina, USA, Uganda, Senegal and Sudan. For all five countries the import of groundnuts is negligible (FAO, 2015). Therefore the raw material for all countries originated from it respective country.

LCI of for ground meal processing based on a crushing process is given below (Ethiopian Embassy, 2008). This resembles a low-tech processing facility.

Table 5-26: Processing of groundnuts (peanuts).

	Unit	Quantity	Comment
Groundnut meal, from crushing, at plant	kg	400	
Crude peanut oil, from crushing, at plant	kg	400	
Inputs			
Groundnuts, with shell, at farm	kg	1000	
Sodium hydroxide (50% NaOH), production mix`	kg	1.904	Proxy for caustic soda
Bleaching earth	kg	8.872	
Electricity	MJ	720	
Furnace oil	L	40	0.97 kg/L. 43.5 MJ/kg
Water	L	40	
Waste and emissions to treatment			
Waste water - untreated, EU-27 S	kg	40	
Landfill of biodegradable waste EU-27 S	kg	200	hulls

Since no satisfactory data on energy content and economic value of ground nut products could be found, proxy data based on soybean are used. Soybean oil has an economic value of 759 €/t and an energy content of 37 MJ/kg, soybean meal has an value of 297 €/t and an energy content of 20 MJ/kg (Schneider & Finkbeiner, 2013).

5.15 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 5-27: 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 5-28: 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	

Table 5-29: Production of HumVi, in Spannenburg. Based on manufacturer data.

	Unit	Quantity	Comment
HumVi, at plant, produced by Vitens in Spannenburg /NL Economic	ton	800	-
Materials/ fuels			
Filtrate from Oldeholtpade for HumVi /NL Economic	ton	290	
Filtrate from Sint Jansklooster for HumVi /NL Economic	ton	360	
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD	kWh	70000	

5.16 Meatless products

Meatless is a flake made from 100% plant-based raw materials, such as wheat, lupin, rice and tapioca. It is a semi-manufactured product and can be included in the recipes of products made with animal-based raw materials, such as processed meat products or cheese, without influencing texture or taste. Meatless flakes are also used in vegetarian products to improve texture and juiciness.

The life cycle of the production of Meatless starts with the cultivation of crops. The wheat for Meatless is cultivated in the Netherlands, the rice is cultivated in China and the tapioca is cultivated in Thailand. Meatless also contains an ingredient based on seaweed (technical aid), which is imported either from China or from France. Meatless flakes are made in the Netherlands in a high volume continuous production system and delivered to the food industry worldwide.

Table 5-30: Production of Meatless hydrated (wet), from wheat. Based on manufacturer data.

	Unit	Quantity	Comment
Meatless, hydrated (wet), wheat based, at plant/NL Economic	kg	1,000	-
Materials/ fuels			
Wheat flour, from dry milling, at plant/NL Economic	kg	160.0	Source 1
Technical aid, for Meatless, at plant/NL Economic	kg	15.0	Source 2
Drinking water, water purification treatment, production mix, at plant, from groundwater RER S System - Copied from ELCD	kg	825.0	-
Nitrogen, via cryogenic air separation, production mix, at plant, gaseous EU-27 S System - Copied from ELCD	kg	1,700	-
Transport, truck >20t, EURO4, 50%LF, default/GLO Economic	tkm	9.8	Transport of Source 1 and 2 to Meatless factory
Transport, freight train, electricity, bulk, 50%LF, flat terrain, default/GLO Economic	tkm	0.35	
Transport, barge ship, bulk, 1350t, 100%LF, default/GLO Economic	tkm	3.325	
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD	kWh	140	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD	MJ	1,129.905	-

Table 5-31: Production of Meatless hydrated (wet), from rice.

Products			
Meatless, hydrated (wet), rice based, at plant/NL Economic	kg	1,000	-
Materials/ fuels			
White rice, from dry milling, at plant/CN Economic	kg	160.0	Source 1
Technical aid, for Meatless, at plant/NL Economic	kg	15.0	Source 2
Drinking water, water purification treatment, production mix, at plant, from groundwater RER S System - Copied from ELCD	kg	825.0	-
Nitrogen, via cryogenic air separation, production mix, at plant, gaseous EU-27 S System - Copied from ELCD	kg	1,700	-
Transport, truck >20t, EURO4, 50%LF, default/GLO Economic	tkm	0.84	transport of Source 2 to Meatless factory
Transport, freight train, electricity, bulk, 50%LF, flat terrain, default/GLO Economic	tkm	0.03	
Transport, barge ship, bulk, 1350t, 100%LF, default/GLO Economic	tkm	0.285	
Transport, sea ship, 10000 DWT, 80%LF, short, default/GLO Economic	tkm	3,058	
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD	kWh	140	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD	MJ	1,129.905	-

Table 5-32: Production of Meatless hydrated (wet), from tapioca. Based on manufacturer data

Products			
Meatless, hydrated (wet), tapioca based, at plant/NL Economic	kg	1,000	-
Materials/ fuels			
Tapioca starch, from processing with use of co-products, at plant/TH Economic	kg	160.0	Source 1
Technical aid, for Meatless, at plant/NL Economic	kg	15.0	Source 2
Drinking water, water purification treatment, production mix, at plant, from groundwater RER S System - Copied from ELCD	kg	825.0	-
Nitrogen, via cryogenic air separation, production mix, at plant, gaseous EU-27 S System - Copied from ELCD	kg	1,700	-
Transport, truck >20t, EURO4, 50%LF, default/GLO Economic	tkm	0.84	Transport of Source 2 to Meatless factory
Transport, freight train, electricity, bulk, 50%LF, flat terrain, default/GLO Economic	tkm	0.03	
Transport, barge ship, bulk, 1350t, 100%LF, default/GLO Economic	tkm	0.285	
Transport, sea ship, 10000 DWT, 80%LF, short, default/GLO Economic	tkm	2,685.9	
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD	kWh	140	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD	MJ	1,129.905	-

Table 5-33: Production of Meatless dehydrated (dry), from rice. Based on manufacturer data

	Unit	Quantity	Comment
Products			
Meatless, dehydrated (dry), rice based, at plant/NL Economic	kg	1,000	-
Materials/ fuels			
White rice, from dry milling, at plant/CN Economic	kg	825.0	Source 1
Technical aid, for Meatless, at plant/NL Economic	kg	75.0	Source 2
Drinking water, water purification treatment, production mix, at plant, from groundwater RER S System - Copied from ELCD	kg	70.0	-
Transport, truck >20t, EURO4, 50%LF, default/GLO Economic	tkm	4.2	Transport of Source 2 to Meatless factory
Transport, freight train, electricity, bulk, 50%LF, flat terrain, default/GLO Economic	tkm	0.2	
Transport, barge ship, bulk, 1350t, 100%LF, default/GLO Economic	tkm	1.4	
Transport, sea ship, 10000 DWT, 80%LF, short, default/GLO Economic	tkm	15,768.2	
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD	kWh	140	-
Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD	MJ	1,129.905	-

The technical aid based on seaweed, is imported either from China or from France. As the environmental impact of this ingredient is not well documented it has been estimated from the electricity consumption for production plus the transport to the Netherlands.

Table 5-34: Technical aid, used in Meatless products. Based on manufacturer data.

Products			
Technical aid, for Meatless, at plant/NL Economic	kg	1,000	-
Materials/ fuels			
Transport, sea ship, 80000 DWT, 80%LF, long, default/GLO Economic	tkm	6,556.5	-
Transport, truck >20t, EURO4, 50%LF, default/GLO Economic	tkm	69.0	-
Transport, freight train, electricity, bulk, 50%LF, flat terrain, default/GLO Economic	tkm	30.5	-
Transport, barge ship, bulk, 550t, 100%LF, default/GLO Economic	tkm	34.5	-
Transport, sea ship, 10000 DWT, 80%LF, short, default/GLO Economic	tkm	249.0	-
Electricity/ heat			
Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD	kWh	14,500	-

Hybrid products using Meatless can be made in two ways: (1) using hydrated (wet) flakes, which are delivered and processed frozen, or (2) rehydrated (dry) flakes. A hybrid product made with hydrated Meatless typically consists of 20% Meatless and 80% meat (other recipes are possible) and does not require the addition of water. When rehydrated dry flakes are used, a hybrid product consists of 3% Meatless, 80% meat and 17% water. The flakes are rehydrated before processing into the meat product. The environmental impact of the manufacturing of the hybrid product has been estimated from the energy consumption of the average meat processing industry.

For this analysis, we used hybrid products in which Meatless made from wheat, rice and tapioca was combined with pork, beef and chicken meat. The beef is assumed to be 35% from dairy cattle and 65% from beef cattle.

The processing data for the manufacturing of the hybrid product are based on the average energy consumption of the Dutch meat processing industry. These figures can vary greatly between different plants:

- 710 kWh (Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD)
- 2532 MJ (Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD)

Hybrid products made with Meatless often contain additional ingredients, such as spices and herbs. These ingredients were not taken into account in this analysis; they are mostly similar to the additional ingredients in the non-hybrid 100% meat products.

The various proposed Meatless products are nutritionally different. Consumers will make their choice from this spectrum depending on their functional and qualitative needs for a certain meal. In addition, meat substitutes can hardly be compared with fresh meat. There is also a difference in nutritional value derived from protein or fat content, which might warrant a comparison based on certain essential nutrients or nutrient density. Product preparation has not been taken into account. Preparation of fresh meat might have a higher environmental impact than preparation of already processed hybrid products and/or meat substitutes.

6 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.

6.1 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 6-1.

Table 6-1: 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, 2006c)	Emissions from livestock and manure management

The herd at the average Dutch dairy farm consists of about 82 dairy cows (Table 6-2). 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 6-2: 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 6-3 for the consumption of electricity and natural gas. The diesel consumption is incorporated in the cultivation and production of roughage.

Table 6-3: 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 6-4. 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 6-5, Table 6-6, Table 6-7), 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 6-4: 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 6-5: 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, 2012)	
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, 2012)	For coverage of the silage

Table 6-6: 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, 2012)	
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 6-7: LCI for the production of grass silage from fresh grass.

Parameter	Unit	Value	Source	Comment
Grass silage	kg	0.34	(Wageningen UR, 2012)	DM = 160 g/kg
Fresh grass	kg	1	(Wageningen UR, 2012)	DM = 470 g/kg
Low density polyethylene	kg	0.001248	(Wageningen UR, 2012)	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 6-8 and Table 6-9).

Table 6-8: 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, consumption mix, at feed compound plant/NL E	kg	0.010
Citrus pulp dried, consumption mix, at feed compound plant/NL E	kg	0.085
Maize gluten meal, consumption mix, at feed compound plant/NL E	kg	0.010
Maize, consumption mix, at feed compound plant/NL E	kg	0.180
Palm kernel expeller, consumption mix, at feed compound plant/NL E	kg	0.135
Rapeseed meal, consumption mix, at feed compound plant/NL E	kg	0.170
Soybean meal, consumption mix, at feed compound plant/NL E	kg	0.110
Soybean hulls, consumption mix, at feed compound plant/NL E	kg	0.015
Sugar beet molasses, consumption mix, at feed compound plant/NL E	kg	0.040
Sugar beet pulp, dried, consumption mix, at feed compound plant/NL E	kg	0.045
Triticale, consumption mix, at feed compound plant/NL E	kg	0.025
Wheat gluten feed, consumption mix, at feed compound plant/NL E	kg	0.035
Wheat bran, consumption mix, at feed compound plant/NL E	kg	0.010
Wheat grain, consumption mix, at feed compound plant/NL E	kg	0.060
Inputs from techno sphere		
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 6-9: 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, consumption mix, at feed compound plant/NL E	kg	0.18	220
Potato pulp pressed fresh+silage, consumption mix, at feed compound plant/NL E	kg	0.14	160
Sugar beet pulp, wet, consumption mix, at feed compound plant/NL E	kg	0.23	220
Soybean meal, consumption mix, at feed compound plant/NL E	kg	0.18	160
Rapeseed meal, consumption mix, at feed compound plant/NL E	kg	0.09	880
Wheat grain, consumption mix, at feed compound plant/NL E	kg	0.09	870
Maize, consumption mix, at feed compound plant/NL E	kg	0.09	870

On the dairy farm, water is used for cleaning as well as for drinking water. Binternet 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 6-4) and the water needs (Table 6-10). The source of drinking water is commonly groundwater.

Table 6-10: Water needs for dairy cattle (Wageningen UR, 2012)

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 6-11). 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 6-11: 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 6-12 can be used to calculate the allocation fractions for the physical allocation approaches: mass and gross energy.

Table 6-12: 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 grazes 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 is not pre-modelled in Agri-footprint but the allocation fractions can be easily manually replaced in Agri-footprint.

6.2 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 6-13, and generic farming parameters in Table 6-14. Table 6-15 lists the feed intake over the whole lifetime of a beef animal as described in the study, and Table 6-16 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 6-15 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 6-17), 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 6-18 and Table 6-19.

Table 6-13: 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 6-14: 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 6-15: 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 6-16: 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 6-17: 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 6-18: Inventory for Irish beef production

Products			
Beef cattle for slaughter, at beef farm/IE	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	1,609.38	Water for drinking
Materials/fuels			
Grass, grazed in pasture/IE	kg	618,996.5	
Grass silage, at beef farm/IE	kg	122,137	
Compound feed beef cattle/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	

Table 6-19: Inventory for emissions from grazing

	Unit	Quantity	Comment
Products			
Grass, grazed in pasture/IE	kg	68,100	
Resources			
Occupation, arable	ha*a	1	
Emissions to air			
Methane, biogenic	kg	5.89	Emissions from manure dropped in pasture during grazing
Dinitrogen monoxide	kg	6.62	Emissions from manure dropped in pasture during grazing
Dinitrogen monoxide	kg	1.41	Emissions from manure dropped in pasture during grazing
Ammonia	kg	51.2	Emissions from manure dropped in pasture during grazing
Emissions to water			
Nitrate	kg	280	Nitrate emissions, due to Use of Manure
Emissions to soil			
Manure, applied (P component)	kg	33.4	Phosphorous emissions, due to Use of Manure

6.3 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 6-20 and Table 6-21. Table 6-22 provides the ration compositions for the piglets, pigs and sows. Table 6-23 lists the emissions that occur due to enteric fermentation and the production and management of pig manure.

*Table 6-20: 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 6-21: 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 6-22: 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, consumption mix, at feed compound plant/NL	%	26	13	25
Barley, consumption mix, at feed compound plant/NL	%	36	21	29
Rye, consumption mix, at feed compound plant/NL	%	0	4	3
Maize, consumption mix, at feed compound plant/NL	%	6	4	2
Triticale, consumption mix, at feed compound plant/NL	%	0	0.5	2
Oat grain, consumption mix, at feed compound plant/NL	%	1	0	0
Wheat feed meal, consumption mix, at feed compound plant/NL	%	2	17	6
Wheat gluten feed, consumption mix, at feed compound plant/NL	%	1	4	1
Maize feed meal, consumption mix, at feed compound plant/NL	%	0	2	1
Sugar beet molasses, consumption mix, at feed compound plant/NL	%	1	1	1
Sugar beet pulp, dried, consumption mix, at feed compound plant/NL	%	1	5	1
Palm oil, consumption mix, at feed compound plant/NL	%	1	1	1.5
Soybean, consumption mix, at feed compound plant/NL	%	4	0	0
Soybean meal, consumption mix, at feed compound plant/NL	%	13	4.5	8
Soybean hulls, consumption mix, at feed compound plant/NL	%	0	5.5	0.5
Rapeseed meal, consumption mix, at feed compound plant/NL	%	2	4	10
Sunflower seed meal, consumption mix, at feed compound plant/NL	%	2	3	4
Palm kernel expeller, consumption mix, at feed compound plant/NL	%	0	8	2.5
Fat from animals, from dry rendering, at plant/NL	%	0	0.5	0.5
Other	%	4	2	2
Total	%	100	100	100

Table 6-23: 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, 2006c)	Note that emissions reduction systems are in place (see Table 6-24) (Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(Hoek & Schijndel, 2006)(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 6-24) 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, 2006c)	
Particulates PM10	56.1	120.8		Note that emissions reduction systems are in place (seeTable 6-24) 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 6-24.

Table 6-24: 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%	

6.4 Poultry

6.4.1 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 6-25) 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 6-25: 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 6-26: 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 6-27. 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 6-27: Feed rations for laying hens.

Feed Ingredient	Unit	Laying hens	
		<17 weeks	>17 weeks
Barley, consumption mix, at feed compound plant/NL	%	1.51	1.11
Maize, consumption mix, at feed compound plant/NL	%	38.6	32.80
Wheat grain, consumption mix, at feed compound plant/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, consumption mix, at feed compound plant/NL	%	15.53	13.45
Sunflower seed meal, consumption mix, at feed compound plant/NL	%	2.61	3.22
Tapioca, consumption mix, at feed compound plant/NL	%	0.91	1.46
Sugar cane molasses, consumption mix, at feed compound plant/NL	%	0.05	0.11
Palm oil, consumption mix, at feed compound plant/NL	%	0	0.004
Fat from animals, consumption mix, at feed compound plant/NL	%	3.44	3.41
Pea dry, consumption mix, at feed compound plant/NL	%	1.17	2.15
Soybean, heat treated, consumption mix, at feed compound plant/NL	%	5.62	2.67
Soybean, consumption mix, at feed compound plant/NL	%	0	0.26
Crushed stone 16/32, open pit mining, production mix, at plant, undried RER	%	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 6-28 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), seeTable 6-29.

Table 6-28: 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)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(CBS, 2011)(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, 2006c)	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 6-29: 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%

6.4.2 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 6-30.

Table 6-30: Key parameters in the system for breeding of broiler parents (<20 weeks). a.p. = animal place. Based on (Wageningen UR, 2013).

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

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 6-31. 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 6-31: 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	0.005	
	Eggs for hatching	€/ kg egg	0.1867	

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 6-32).

Table 6-32: 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 a weeks to become broilers, which are slaughtered for meat production. This requires energy consumption (electricity and natural gas), water consumption and feed consumption (Table 6-33).

Table 6-33: 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 6-34) 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 6-34: Feed rations for broiler parents and broilers.

Feed Ingredient	Unit	Broiler parents <20 weeks	Broiler parents >20 weeks	Broilers
Barley, consumption mix, at feed compound plant/NL	%	3	7	0
Maize, consumption mix, at feed compound plant/NL	%	26	17	25
Wheat grain, consumption mix, at feed compound plant/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, consumption mix, at feed compound plant/NL	%	6.5	3	31
Sunflower seed meal, consumption mix, at feed compound plant/NL	%	6	13	0.5
Rapeseed meal, consumption mix, at feed compound plant/NL	%	5.5	6	11
Oat grain, consumption mix, at feed compound plant/NL	%	0.5	1	0.5
Palm oil, consumption mix, at feed compound plant/NL	%	0.5	0.25	3
Fat from animals, consumption mix, at feed compound plant/NL	%	2.5	1	4
Pea dry, consumption mix, at feed compound plant/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 6-35 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 6-36.

Table 6-35: 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, 2006c) (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, 2006c)	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, 2006c)	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 6-36: Stable types and reduction efficiency for ammonia and particulate matter for broiler parents and broilers.

		Broiler parents		Broilers
		<20 weeks	>20 weeks	
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%

6.5 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 6-37.

Table 6-37: 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 6-38 to Table 6-40.

The water use is not split up transparently in the ‘ketenkaarten[3]’, 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 6-41.

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

Table 6-38: 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 6-39: 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 6-40: 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 6-41: 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

6.6 PEF compliant cattle processes

The European Commission (EC) recommends two methods to measure the environmental performance of products and organizations: (1) the Product Environmental Footprint (PEF) and (2) the Organization Environmental Footprint. In this context, EC initiated a piloting phase for the development of Product Environmental Footprint Category Rules (PEFCRs) in order to provide category-specific guidance for calculating and reporting life cycle environmental impacts of products.

In 2014, 11 food and beverage PEF pilots started and a Cattle Model Working Group (CMWG) was initiated. The objective of this group was to harmonize LCA PEF methodology at farm and slaughterhouse level by reaching a consensual agreement regarding:

- Allocation of upstream burdens among the outputs at farm and among outputs at slaughterhouse level,
- Models for methane emission from enteric fermentation,
- Models for emissions from manure management (including methane, nitrous oxide, ammonia, nitric oxide, non-methane volatile compounds and particulate matter emissions) and
- A model for carbon sequestration/release in grassland systems.

The results of the CMWG and the methodologies are to be used as baseline approach in feed, dairy, meat, leather and pet food pilots throughout the pilot process and are described in a report (JRC & European Commission, 2015).

Agri-footprint contains processes which take into account the CMWG baseline approaches (PEF compliant processes) for:

- Dairy farm systems in the Netherlands,
- Irish beef,
- Slaughterhouse for dairy cattle,
- Slaughterhouse for beef cattle.

The main differences between the basic Agri-footprint and the CMWG baseline approaches are (1) the allocation between co-products and (2) the calculation of certain types of emissions (see Table 6-42). For example, the CMWG baseline approach deals with the calculation of emissions due to livestock manure management in the stable but it excludes the manure emissions on the soil. When the Agri-footprint approach complies with the CMWG baseline approach or uses a higher Tier level, the Agri-footprint approach has been used in the PEF compliant processes. In other cases, the CMWG baseline approach has been used in the PEF compliant processes.

The PEF compliant processes are included in all libraries of the Agri-footprint. This means that when the CMWG baseline approach has requirements regarding allocation, the allocation of preceding processes not covered by the CMWG is in line with the specific Agri-footprint library.

Table 6-42: Main differences between Agri-footprint approach and CMWG baseline approach

Topic	Agri-footprint	CMWG baseline approach
Allocation on the dairy farm	Economic/ Mass/ Gross energy content	IDF allocation
Allocation in the slaughterhouse	Economic/ Mass/ Gross energy content	Economic allocation with predefined allocation fractions
CH4 emissions due to enteric fermentation	IPCC guidelines Tier 3	IPCC guidelines minimum Tier 2
CH4 emissions due to manure management	IPCC guidelines Tier 2	IPCC guidelines minimum Tier 2
Direct N2O emissions from livestock manure	IPCC guidelines Tier 2	IPCC guidelines minimum Tier 1
Indirect N2O emissions from livestock manure	IPCC guidelines Tier 2	IPCC guidelines minimum Tier 1
NH3 emissions from livestock manure	IPCC guidelines Tier 2	EMEP/EEA guidelines minimum Tier 2
NO emissions from livestock manure	-	EMEP/EEA guidelines minimum Tier 2
NMVOC emissions from livestock manure	-	EMEP/EEA guidelines minimum Tier 2
Particulate matter emissions from livestock manure	EMEP/EEA guidelines minimum Tier 3	EMEP/EEA guidelines minimum Tier 2
Soil C stocks in grassland	Based on FAO statistics and IPCC calculation rules, following the PAS 2050-1 methodology	Not taken into account unless land use change happened less than 20 years before assessment year. The use IPCC Tier 1

7 Background processes

7.1 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 ELCD database.

7.1.1 Electricity grids outside Europe

As grids from outside Europe are not available in the ELCD database, proxy grids needed to be created, seeTable 7-1. 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.

Table 7-1: 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

7.2 Transport processes

7.2.1 Road

Fuel consumption for road transport is based on primary activity data of multiple types of vehicles (Table 7-2). 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 7-3). 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 7-2: 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 7-3: 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.

7.2.2 Water

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

7.2.2.1 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 7-4).

Table 7-4: 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.

7.2.2.2 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.

Step 9: Calculate the fuel consumption per phase

Fuel consumption (GJ) per phase i =

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

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

Step 11: 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 7-5. (Klein et al., 2012a).

Table 7-5: 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.

7.2.3 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 7-6 displays the values of the wagon specifications which have been used to calculate the fuel consumption of freight trains transporting bulk or containers.

Table 7-6 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., 2012a) of www.emisieregistratie.nl,which have been calculated based on the methodology by (Klein et al., 2012b).

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.

7.2.4 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 7-7.

Table 7-7: 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 7-8, Table 7-9 and Table 7-10. 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., 2012a) from www.emisieregistratie.nl, which have been calculated based on the methodology by (Klein et al., 2012b).

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 7-7 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 7-8: 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 7-9: 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 7-10: 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

7.3 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.

7.3.1 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 7-11: 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	-

7.3.2 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 7-12: 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

7.3.3 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 7-13).

Table 7-13: 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 7-14, Table 7-15 and Table 7-16, respectively. Note that quantities are listed ‘as is’, and not the chemical compound.

Table 7-14: 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 7-15: 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 7-16: 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	-

7.3.4 Phosphoric Acid

The inventory for phosphoric acid production is based on a publication by Kongshaug (1998) (Table 7-17).

Table 7-17: 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

7.3.5 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 7-18).

Table 7-18: 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	

7.3.6 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 inTable 7-19.

Table 7-19: 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	-

7.3.7 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.

7.4 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. Where Ecoinvent 2.2 “splits” fertilizers that contain N and P, Agri-footprint leaves them combined. This avoids confusion for users but requires some consideration when Agri-footprint fertilizers are replaced by Ecoinvent equivalents and vice versa. Figure 7-1 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 7-20 to Table 7-33. Some other important intermediate products (phosphoric acid and sulfuric acid) are described in previous sections and listed in Table 7-17 and Table 7-18.

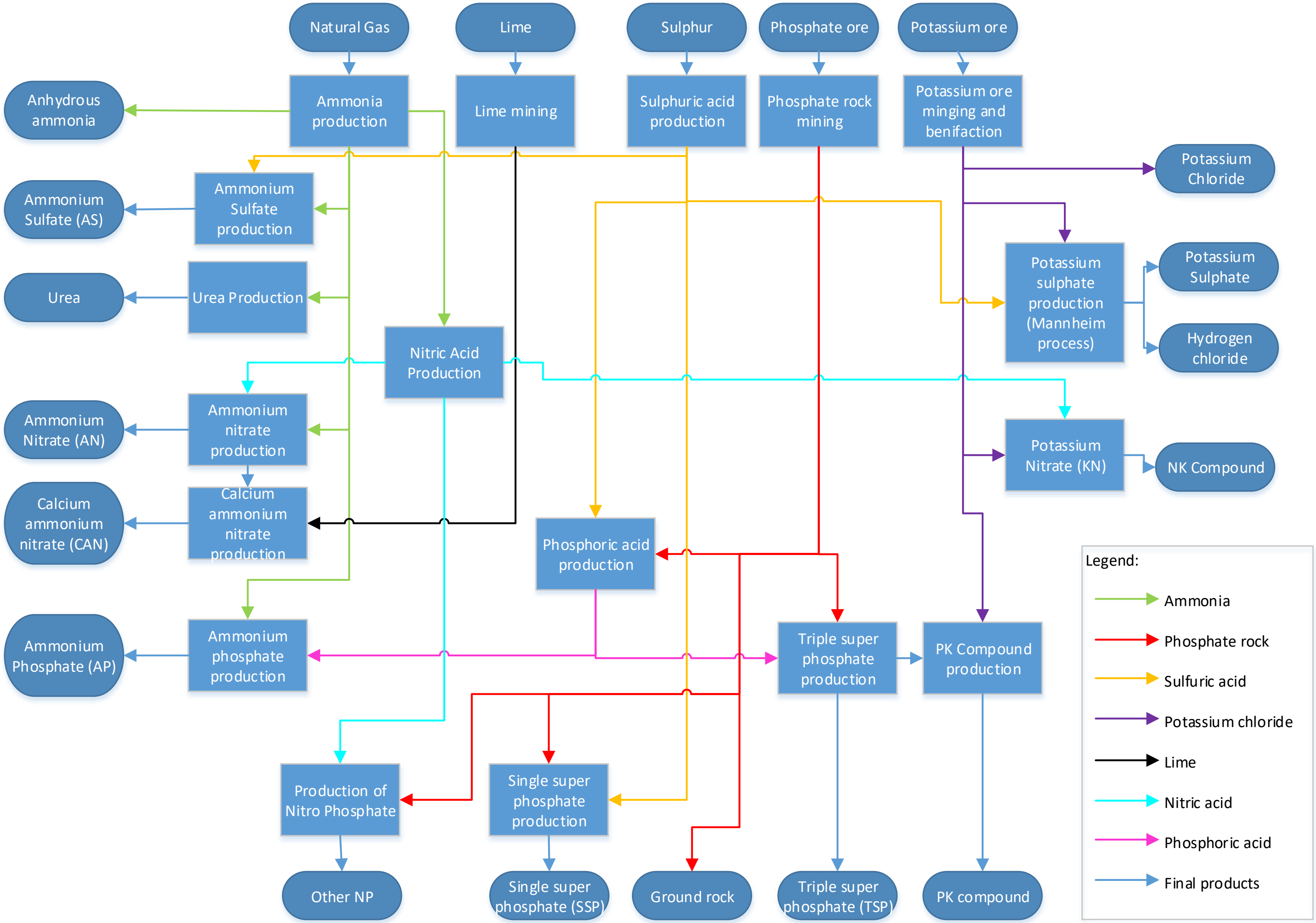

Figure 7-1: Product flow diagram for fertilizer production. The colored lines indicate specific intermediate flows (see legend). Raw materials are listed on the top of the figure, N fertilizers are listed on the left, P fertilizers on the bottom, K fertilizers on the right. Figure based on description in Kongshaug (1998).

Table 7-20: 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 7-21: 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 7-22: 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 7-23: 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 7-24: 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 7-25: 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 7-26: 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 7-27: 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 7-28: 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 7-29: 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 7-30: 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 7-31: 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 7-32: 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 7-33: 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	-

7.5 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[4]. 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 waste water 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).

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[4] 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 7-34: 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	

7.6 Production of Pesticides

7.6.1 Introduction

The active ingredient application rates (kg/ha) during crop cultivation are already inventoried by Agri-footprint for all crop-country combinations present in the database (see section 3.7). The average concentration of active ingredients in different pesticide formulations (e.g. granulates, wet powder etc.) has been used to back-calculate the amount of pesticide production required (kg product/ha). All other substances (besides the active ingredient) are called inert ingredients. Manufacturing of active ingredients is based on most well established source (Green, 1987), where direct and indirect inputs of the active ingredient manufacturing process are reported. The composition of inert ingredients is explained below.

The functional unit is 1kg of pesticide produced (active ingredient and inert ingredient). The inventory comprises the material and energy input of active ingredients manufacturing, the production of inert ingredients, the energy input for the production of pesticide (i.e. active and inert ingredients into a final product), the production of packaging material for pesticides and the emissions due to pesticide production.

7.6.2 System boundary

The system boundary of this LCI is defined by the following three processes (Figure 7-2):

1. Active ingredient manufacturing; this process includes the reaction of several raw materials to produce the active ingredients of pesticides. During this process, cooling and/or heating is required. These inputs are modelled based on (Green, 1987). Emissions, water effluents and residues are also generated in this phase.
2. Inert ingredient production; this process include the production of substances present in pesticide formulation. The production of these chemicals is readily available by ELCD database.
3. Pesticide production; this process includes the mixing, blending and/or diluting the active ingredients with other chemicals such as adjuvants or solvents (i.e. inert ingredients). This formulation gives an optimal efficiency, easy application and it should minimize environmental and health impacts.
4. Pesticide packaging to final marketable product; this process includes the production of packaging material.

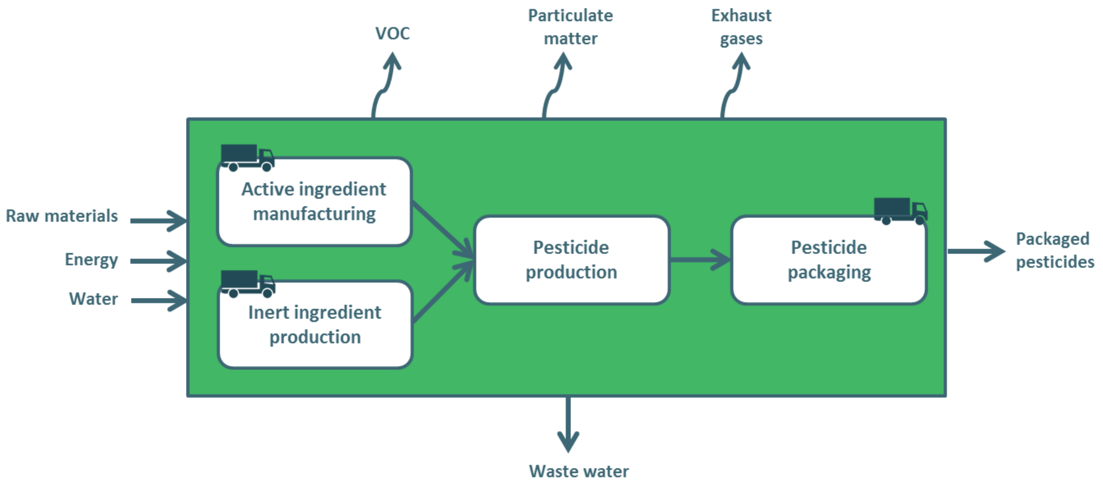

Figure 7-2 Diagram of system boundaries of the LCI for pesticides

In the table below, activity data and elementary flows included and excluded are given.

Table 7-35 Activity data and elementary flows included and excluded

Included	Excluded	Reasoning for excluding
Active ingredient manufacturing (material and energy input).	Specific chemicals and capital goods during active ingredients manufacturing.	Not available in Green 1987.
Inert ingredients production.	Capital goods in inert ingredients production.	Not inventoried by ELCD or AFP database.
Transportation from plant to farm is included for total chemical input during cultivation.	Upstream plant-to-plant and/or plant-to-warehouse distribution of chemicals.	Insignificant contribution.
Transportation for the production of packaging material is indirectly included via the ELCD database.	Energy for packing the pesticides.	Insignificant contribution.
Transport, mining and exploration processes for the energy carrier supply chain are indirectly included via the ELCD database.		
Water use during pesticide manufacturing (proxy data were used).		
Energy for pesticide production.		
Emissions to water due to active ingredient manufacturing.		

7.6.3 Pesticide production (active and inert ingredients)

Pesticides are available in different formulation and they may include different substances depending on their type and brand. Example of substance available in pesticide formulation are:

- Pesticide active ingredient that controls the target pest;
- Carrier, such as an inorganic solvent, organic solvent or mineral clay;
- Surface-active ingredient, such as stickers and spreaders; and/or
- Other ingredients, such as stabilizers, dyes and chemicals that improve or enhance pesticidal activity

The main pesticide structure is shown in Figure 7-3. Pesticide is made of **active ingredients** and **inert ingredients** where inert ingredients are carriers and adjuvants. A carrier is an inert liquid or solid added to an active ingredient to prepare a pesticide formulation while adjuvants have no pesticidical activity but they rather ease the mixing.

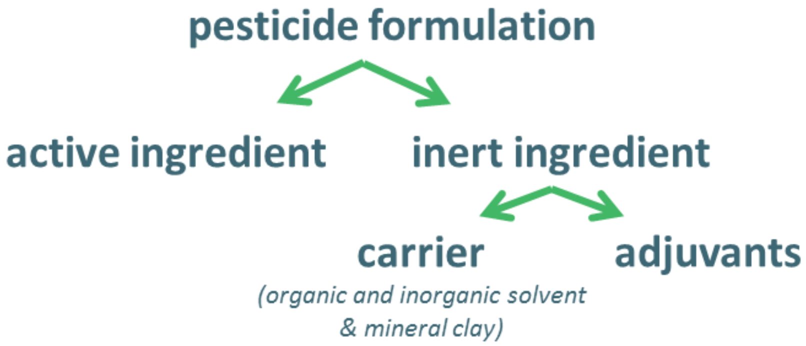

Figure 7-3 Main pesticide formulation

The concentration of active ingredients (a.i.) in pesticides has been collected through bibliographic research. The concentration of the inert ingredients is modelled as the remaining concentration of that of active ingredients *(i.e. 100% - % a.i.)*.

7.6.3.1 Active ingredients

The most well established source of information on pesticide manufacturing is Green (1987). A series of computer programs developed by Green (1987) have been used to estimate the energies needed for both direct and indirect input including that to build and maintain plants and equipment, feed and transport workers and disposal of waste.

Indirect energy input is the sum of the inherent energies of all the materials derived from fossil fuels that are used in the manufacturing process of active ingredients. Process energy is the energy required in the manufacturing process of the chemicals such as heating, creating pressure and cooling, plus the energy needed to create and transmit that energy to the manufacturing process. This is called direct energy input. The original data is listed in Annex II.

Of course not all of the active ingredients are covered by the Green 1987 list. When an active ingredient was not covered by Green (1987), it was classified based on its family type (if known by Green 19987) (e.g. organophosphorus herbicides, carbamate insecticides, benzimidazole fungicides), else based on the overall pesticide category (i.e. herbicide, insecticide, fungicide). Therefore when active ingredient specific data was not available we used the average direct and indirect inputs of each family, or category to derive a representative proxy-data for its manufacturing.

Based on active ingredient concentration, the required amount to be manufactured is calculated. The most well established source of information on active ingredient manufacturing is Green (1987).

As a matter of fact, 59 processes have been modelled in total:

- 33 number of active ingredients to be modelled (based on Green, 1987)
- 22 number of family types to be modelled *(covering 133 active ingredients)*
- 4 number of categories to be modelled (i.e. herbicide, fungicide, insecticide and plant growth regulator) *(covering 191 active ingredients)*

7.6.3.2 Inert ingredients

Most pesticide products contain substances in addition to the active ingredient, known as inert ingredients. Inert ingredients are substances intentionally included in the pesticide production in order to get a more desirable formulation. Inert ingredients are organic or mineral solvents and adjuvants. An adjuvant is any compound that is added to a pesticide formulation to facilitate the mixing, application, or effectiveness of that pesticide.

Since the type of inert ingredients and ration among them can differ a lot per pesticide type and among brands and since this information is not available for all products, the selection of inert ingredients was based on pesticide formulations that were possible to collect from several sources. Therefore a default, average mix of inert ingredients was developed which is the same for all pesticides.

The average mix of inert ingredients is made up of benzene and naphtha used to model the share of oil-based solvent and kaolin to model the share of mineral clay. Moreover, soap stock from coconut oil refining is used as an approximation to an emulsifier (i.e. adjuvant) and drinking water is used as an organic solvent. We have assumed equal concentration among the different types of inert ingredients, i.e. 25% oil-based solvent, 25% mineral solvent, 25% adjuvant and 25% water, as shown in the table below.

Table 7-36: Inert ingredients composition of pesticides in Agri-footprint

Process used to model inert ingredients	Type of inert ingredient	Share of specific inert compound to the inerts composition
Benzene, prod. mix, liquid EU-27 S & Naphtha, from crude oil, consumption mix, at refinery EU-15 S	Oil-based solvent	25%
Soap stock (coconut oil refining)	Adjuvant	25%
Kaolin coarse filler , production, at plant EU-27 S	Mineral solvent	25%
Drinking water, water purification treatment, production mix, at plant, from surface water RER S	Inorganic solvent	25%

7.6.4 Water use for pesticide production

Data used is based on a study from Silva and Kulay (2003) which refers to the production of SSP fertilizer. That was the best proxy found. Hence, 1425 kg of water per ton of pesticide is included in all LCIs of pesticide manufacturing.

7.6.5 Energy for pesticide production (i.e. formulation and packaging to final product)

Green (1987) estimated the total energy use for three types of pesticide types: 20 GJ per tonne of emulsifiable concentrates, 30GJ per tonne of wettable powders and 10 GJ per tonne of granules. For the LCIs we have used an average energy consumption of 20MJ/kg active ingredient. For packaging of pesticide we have used the Agri-footprint process of packaging of fertilizers, which equals to 0.06 PP (polypropylene) and 0.0225 kg HDPE (high density polyethylene)per 25 kg produced fertilizer. According to Green (1987), energy involved in packaging the formulated pesticide into cans and bags, amounts to about 2GJ per tonne of pesticide.

7.6.6 Emissions to water due pesticide manufacturing

Data on emissions to water are based on the Environmental, Health and Safety (EHS) Guidelines for pesticide manufacturing, formulation and packaging (WBG, 2007; tables 2 and 4). Effluent guidelines reported in tables 2 and 4 of the publication are applicable for direct discharge of treated effluents to surface waters and should be achieved without dilution, at least 95% of the time that the plant or unit is operating. We have used these guidelines to calculate the maximum pollution allowed based on a COD load of 6.5 kg per ton of active ingredient (WBG, 2007; table 4).

Therefore, the following effluent pollutants have been used to model the effluent levels of pesticide production, based on the effluent guideline value of 6.5kg COD/ ton of active ingredient:

- BOD5, Biological Oxygen Demand
- COD, Chemical Oxygen Demand
- Suspended solids, unspecified
- Petroleum oil
- AOX, Adsorbable Organic Halogen as Cl
- Phenol
- Arsenic
- Chromium
- Chromium VI
- Copper
- Hydrocarbons, chlorinated
- Nitrogen, organic bound
- Mercury
- Zinc
- Ammonia
- Phosphorus, total

The same publication reports also air emission levels for pesticide manufacturing which are associated with steam and power generation activities. However, energy generation is taken into account by Green (1987), so we did not use these emission levels in order to avoid double counting. Waste generation is also taken by WBG (2007) and is determined to 200 kg per ton formulated active ingredient.

7.7 Capital goods

7.7.1 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 7-37: 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 mm^2 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	Windows (BAD PROXY?)
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 utilisation of tractors per year and the economic lifetime of tractors. Tractors are estimated to have an utilisation of 600 hours per year and an economic lifetime of 12 years (Wageningen UR, 2015b). Hereby the production of tractors is evenly divided over 7,200 operational hours during its lifetime.

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List of tables and figures

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Appendix A. List of crop and country combinations

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

Crop	Countries
Barley	AR, AT, AU, BE, BG, BR, CA, CH, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IT, LT, LV, MX, NL, PL, PT, RO, SE, SK, UA, UK, ZA
Dry Beans	NL, US, ZA
Broad Beans	AU, FR
Broccoli	FR, NL
Carrot	BE, NL
Cassava	TH
Cauliflower	ES, NL
Chickpea	AU, IN, US
Chicory root	BE, NL
Coconut	ID, IN, PHP
Potato	AT, BE, BG, CH, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NL, NO, PL, PT, RO, SE
Curly kale	ES, NL
Groundnuts	AR, CN, ID, IN, MX, US
Lentil	AU, CA
Linseed	AT, BE, DE, IT, LT, LV, UK
Lupine	AU, DE
Maize	AR, BE, BG, BR, CA, CN, CZ, DE, ES, FR, GR, HU, ID, IN, IT, MX, PH, PK, PL, PT, RO, SK, TH, UA, US, VN, ZA
Oat	AT, BE, BG, CA, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NL, NO, PL, PT, RO, SE, SK, UA, UK, US
Oil palm	ID, MY
Pea	AU, CA, DE, ES, FR, IT, RO, SE, UK
Pigeon Pea	IN
Rapeseed	AU, BE, BG, CA, CH, CN, CZ, DE, DK, ES, FI, FR, GR, HU, IN, IT, LT, LV, NL, NO, PL, RO, SE, SI, UA, UK, US
Rice	CN
Rye	AT, BE, BG, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NO, PL, PT, SE, SK, UA
Sorghum	AR, AU, IN, MX, US, ZA
Soybean	AR, BR, CA, CN, FR, HU, IN, IT, MX, PL, RO, US
Spinach	BE, NL
Sugar beet	AT, BE, CH, CZ, DE, DK, ES, FI, FR, HU, IT, LT, NL, PL, RO, SE, UA, UK

Crop	Countries
Sugar cane	AR, AU, BR, CN, CO, ID, IN, PH, PK, SD, TH, US, VE
Sunflower	AR, BG, CN, CZ, ES, FR, GR, HU, IT, RO, UA
Triticale	AT, CH, CZ, DE, ES, FR, HU, LT, LV, NL, PL, PT, RO, SE, SK
Wheat	AR, AT, AU, BE, BG, BR, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IN, IT, LT, LV, MX, NL, NO, PK, PL, PT, RO, SE, UA, UK

Appendix B. List of products in Agri-footprint 2.0.

Table B-1: List of products included in the Agri-footprint 2.0

Product	Countries
Acrylonitrile-butadiene-styrene granulate (ABS), production mix, at plant RER System - Copied from ELCD	
Activated carbon, at plant	RER
Ammonia, as 100% NH3 (NPK 82-0-0), at plant	RER
Ammonia, as 100% NH3 (NPK 82-0-0), at regional storehouse	RER
Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), at plant	RER
Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), at regional storehouse	RER
Ammonium sulphate, as 100% (NH4)2SO4 (NPK 21-0-0), at plant	RER
Ammonium sulphate, as 100% (NH4)2SO4 (NPK 21-0-0), at regional storehouse	RER
Animal meal, from dry rendering, at plant	NL
Asbestos, at mine	RER
Barley grain, at farm	AR, AT, AU, BE, BG, BR, CA, CH, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IT, LT, LV, MX, NL, PL, PT, RO, SE, SK, UA, UK, ZA
Barley grain, consumption mix, at feed compound plant	IE, NL
Barley grain, dried, at farm	AR, AT, AU, BE, BG, BR, CA, CH, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IT, LT, LV, MX, NL, PL, PT, RO, SE, SK, UA, UK, ZA
Barley straw, at farm	AR, AT, AU, BE, BG, BR, CA, CH, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IT, LT, LV, MX, NL, PL, PT, RO, SE, SK, UA, UK, ZA
Barley straw, consumption mix, at feed compound plant	NL
Beans, dry, at farm	NL, US, ZA
Beans, dry, canned, at plant	NL
Beef cattle for slaughter, at beef farm	IE
Beef cattle for slaughter, at beef farm, PEF compliant	IE
Beef co-product, Cat.1/2 and waste, from beef cattle, at slaughterhouse, PEF compliant	IE
Beef co-product, Cat.1/2 and waste, from dairy cattle, at slaughterhouse, PEF compliant	NL
Beef co-product, Cat.3 by-products, from beef cattle, at slaughterhouse, PEF compliant	IE

Beef co-product, Cat.3 by-products, from dairy cattle, at slaughterhouse, PEF compliant	NL
Beef co-product, feed grade, from beef cattle, at slaughterhouse	IE
Beef co-product, feed grade, from dairy cattle, at slaughterhouse	NL
Beef co-product, food grade bones, from beef cattle, at slaughterhouse, PEF compliant	IE
Beef co-product, food grade bones, from dairy cattle, at slaughterhouse, PEF compliant	NL
Beef co-product, food grade fat, from beef cattle, at slaughterhouse, PEF compliant	IE
Beef co-product, food grade fat, from dairy cattle, at slaughterhouse, PEF compliant	NL
Beef co-product, food grade, from beef cattle, at slaughterhouse	IE
Beef co-product, food grade, from dairy cattle, at slaughterhouse	NL
Beef co-product, hides and skins, from beef cattle, at slaughterhouse, PEF compliant	IE
Beef co-product, hides and skins, from dairy cattle, at slaughterhouse, PEF compliant	NL
Beef co-product, other, from beef cattle, at slaughterhouse	IE
Beef co-product, other, from dairy cattle, at slaughterhouse	NL
Beef meat, fresh, from beef cattle, at slaughterhouse	IE
Beef meat, fresh, from beef cattle, at slaughterhouse, PEF compliant	IE
Beef meat, fresh, from dairy cattle, at slaughterhouse	NL
Beef meat, fresh, from dairy cattle, at slaughterhouse, PEF compliant	NL
Beef, for Meatless hybrid, at plant	NL
Bleaching earth, at plant	RER
Blood meal, spray dried, consumption mix, at feed compound plant	NL
Blood meal, spray dried, from blood processing, at plant	NL
Brewer's grains, consumption mix, at feed compound plant	NL
Brewer's grains, wet, at plant	NL
Broad bean, at farm	AU, FR
Broad bean, hulls, at plant	NL
Broad bean, meal, at plant	NL
Broccoli, at farm	FR, NL
Broiler parents <20 weeks, breeding, at farm	NL
Broiler parents >20 weeks, for slaughter, at farm	NL
Broilers, for slaughter, at farm	NL

Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at plant	RER
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at regional storehouse	RER
Calcium ammonium nitrate (CAN), Nutramon, (NPK 27-0-0), at OCI Nitrogen plant	NL
Calves, at dairy farm	NL
Calves, at dairy farm, PEF compliant	NL
Carrot, at farm	BE, NL
Cassava peels, fresh, from processing with use of co-products, at plant	TH
Cassava pomace (fibrous residue), fresh, from processing with use of co-products, at plant	TH
Cassava root dried, from tapioca processing, at plant	TH
Cassava, at farm	TH
Cauliflower, at farm	ES, NL
Cheese, from cheese production, at plant	NL
Chicken co-product, feed grade, at slaughterhouse	NL
Chicken co-product, food grade, at slaughterhouse	NL
Chicken co-product, other, at slaughterhouse	NL
Chicken meat, fresh, at slaughterhouse	NL
Chickpea, at farm	AU, IN, US
Chickpea, canned, at plant	NL
Chicory root, at farm	BE, NL
Chlorine gas, from amalgam technology, at plant	RER
Chlorine gas, from diaphragm technology, at plant	RER
Chlorine gas, from membrane technology, at plant	RER
Chlorine gas, production mix	RER
Citrus pulp dried, consumption mix, at feed compound plant	NL
Citrus pulp dried, from drying, at plant	BR, US
Coconut copra meal, consumption mix, at feed compound plant	NL
Coconut copra meal, from crushing, at plant	ID, IN, PH
Coconut husk, from dehusking, at plant	ID, IN, PH
Coconut, at farm	ID, IN, PH
Coconut, dehusked, from dehusking, at plant	ID, IN, PH

Combustion of natural gas, consumption mix, at plant	NL
Compound feed beef cattle	IE
Compound feed breeding broiler parents <20 weeks	NL
Compound feed breeding laying hens <17 weeks	NL
Compound feed broiler parents >20 weeks	NL
Compound feed broilers	NL
Compound feed dairy cattle	NL
Compound feed laying hens >17 weeks	NL
Consumption eggs, broiler parents >20 weeks, at farm	NL
Consumption eggs, laying hens >17 weeks, at farm	NL
Consumption potato, at farm	NL
Cows for slaughter, at dairy farm	NL
Cows for slaughter, at dairy farm, PEF compliant	NL
Cream, full, from processing, at plant	NL
Cream, skimmed, from processing, at plant	NL
Crude coconut oil, from crushing, at plant	ID, IN, PH
Crude maize germ oil, from wet milling (germ oil production, pressing), at plant	DE, FR, NL, US
Crude maize germ oil, from wet milling (germ oil production, solvent), at plant	DE, FR, NL, US
Crude palm kernel oil, from crushing, at plant	ID, MY
Crude palm oil, from crude palm oil production, at plant	ID, MY
Crude rapeseed oil, from crushing (pressing), at plant	BE, DE, NL
Crude rapeseed oil, from crushing (solvent), at plant	BE, DE, FR, NL, PL, US
Crude rice bran oil, from rice bran oil production, at plant	CN
Crude soybean oil, from crushing (pressing), at plant	AR, BR, NL
Crude soybean oil, from crushing (solvent), at plant	AR, BR, DE, ES, NL, US
Crude soybean oil, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL
Crude sunflower oil, from crushing (pressing), at plant	AR, CN, UA
Crude sunflower oil, from crushing (solvent), at plant	AR, CN, UA
Curly kale, at farm	ES, NL
Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), at plant	RER

Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), at regional storehouse	RER
Dolomite, milled, at mine	RER
Electricity mix, AC, consumption mix, at consumer, < 1kV	AR, AU, BR, CA, CN, ID, IN, MY, PH, PK, RU, SD, UA, US, VN
Energy, from diesel burned in machinery	RER
Ethanol, from ethene, at plant	RER
Ethene (ethylene), from steam cracking, production mix, at plant, gaseous EU-27 S System - Copied from ELCD	
Fat from animals, consumption mix, at feed compound plant	NL
Fat from animals, from dry rendering, at plant	NL
Fatty acid distillates (palm oil production)	NL
Fodder beet, at farm	NL
Fodder beets cleaned , consumption mix, at feed compound plant	NL
Fodder beets cleaned, from cleaning, at plant	NL
Fodder beets dirty, consumption mix, at feed compound plant	NL
Food grade fat, from fat melting, at plant	NL
Formaldehyde, at plant	RER
Grass silage, at beef farm	IE
Grass silage, at dairy farm	NL
Grass, at beef farm	IE
Grass, at dairy farm	NL
Grass, grazed in pasture	IE
Greaves meal, consumption mix, at feed compound plant	NL
Greaves meal, from fat melting, at plant	NL
Green bean, at farm	KE, MA, NL
Groundnuts, with shell, at farm	AR, CN, ID, IN, MX, US
Hatching eggs, broiler parents >20 weeks, at farm	NL
Hexane, at plant	RER
Hydrochloric acid, Mannheim process (30% HCl), at plant	RER
Hydrogen gas, from amalgam technology, at plant	RER
Hydrogen gas, from diaphragm technology, at plant	RER

Hydrogen gas, from membrane technology, at plant	RER
Laying hens <17 weeks, breeding, at farm	NL
Laying hens >17 weeks, for slaughter, at farm	NL
Lentil, at farm	AU, CA
Lentil, canned, at plant	NL
Lime fertilizer, at plant	RER
Lime fertilizer, at regional storehouse	RER
Lime fertilizer, from sugar production, at Suiker Unie plants	NL
Lime fertilizer, from sugar production, at plant	DE, FR, PL
Linseed, at farm	AT, BE, DE, IT, LT, LV, UK
Liquid urea-ammonium nitrate solution (NPK 30-0-0), at plant	RER
Liquid urea-ammonium nitrate solution (NPK 30-0-0), at regional storehouse	RER
Liquid whey, from cheese production, at plant	NL
Lupine, at farm	AU, DE
Lupine, consumption mix, at feed compound plant	NL
Lupine, hulls, at plant	NL
Lupine, meal, at plant	NL
Maize bran, consumption mix, at feed compound plant	NL
Maize bran, from wet milling (drying), at plant	DE, FR, NL, US
Maize degermed, from wet milling (degermination), at plant	DE, FR, NL, US
Maize fibre/bran, dewatered, from wet milling (fibre dewatering), at plant	DE, FR, NL, US
Maize fibre/bran, wet, from wet milling (grinding and screening), at plant	DE, FR, NL, US
Maize flour, from dry milling, at plant	DE, FR, IT, NL, PL, US
Maize germ meal expeller, consumption mix, at feed compound plant	NL
Maize germ meal expeller, from wet milling (germ oil production, pressing), at plant	DE, FR, NL, US
Maize germ meal extracted, consumption mix, at feed compound plant	NL
Maize germ meal extracted, from wet milling (germ oil production, solvent), at plant	DE, FR, NL, US
Maize germ, dried, from wet milling (germ drying), at plant	DE, FR, NL, US
Maize germ, wet, from wet milling (degermination), at plant	DE, FR, NL, US
Maize gluten feed, dried, consumption mix, at feed compound plant	NL

Maize gluten feed, from wet milling (glutenfeed production, with drying), at plant	DE, FR, NL, US
Maize gluten feed, high moisture, consumption mix, at feed compound plant	NL
Maize gluten feed, high moisture, from wet milling (glutenfeed production, no drying), at plant	DE, FR, NL, US
Maize gluten meal, consumption mix, at feed compound plant	NL
Maize gluten meal, from wet milling (gluten drying), at plant	DE, FR, NL, US
Maize gluten, wet, from wet milling (gluten recovery), at plant	DE, FR, NL, US
Maize middlings, consumption mix, at feed compound plant	NL
Maize middlings, from dry milling, at plant	DE, FR, IT, NL, PL, US
Maize silage, at dairy farm	NL
Maize solubles, consumption mix, at feed compound plant	NL
Maize solubles, from wet milling (steepwater dewatering), at plant	DE, FR, NL, US
Maize starch and gluten slurry, from wet milling (grinding and screening), at plant	DE, FR, NL, US
Maize starch, consumption mix, at feed compound plant	NL
Maize starch, from wet milling (starch drying), at plant	DE, FR, NL, US
Maize starch, wet, from wet milling (gluten recovery), at plant	DE, FR, NL, US
Maize steepwater, wet, from wet milling (receiving and steeping), at plant	DE, FR, NL, US
Maize, at farm	AR, BE, BG, BR, CA, CN, CZ, DE, ES, FR, GR, HU, ID, IN, IT, MX, PH, PK, PL, PT, RO, SK, TH, UA, US, VN, ZA
Maize, consumption mix, at feed compound plant	IE, NL
Maize, steeped, from wet milling (receiving and steeping), at plant	DE, FR, NL, US
Manure, from cows, at farm	RER
Manure, from pigs, at pig farm	RER
Meat bone meal, consumption mix, at feed compound plant	NL
Meatless hybrid, dehydrated (dry) rice/beef, at plant	NL
Meatless hybrid, dehydrated (dry) rice/chicken, at plant	NL
Meatless hybrid, dehydrated (dry) rice/pork, at plant	NL
Meatless hybrid, hydrated (wet) rice/beef, at plant	NL
Meatless hybrid, hydrated (wet) rice/chicken, at plant	NL
Meatless hybrid, hydrated (wet) rice/pork, at plant	NL
Meatless hybrid, hydrated (wet) tapioca/beef, at plant	NL

Meatless hybrid, hydrated (wet) tapioca/chicken, at plant	NL
Meatless hybrid, hydrated (wet) tapioca/pork, at plant	NL
Meatless hybrid, hydrated (wet) wheat/beef, at plant	NL
Meatless hybrid, hydrated (wet) wheat/chicken, at plant	NL
Meatless hybrid, hydrated (wet) wheat/pork, at plant	NL
Meatless, dehydrated (dry), rice based, at plant	NL
Meatless, hydrated (wet), rice based, at plant	NL
Meatless, hydrated (wet), tapioca based, at plant	NL
Meatless, hydrated (wet), wheat based, at plant	NL
Mercury, at plant	RER
Milk powder skimmed, consumption mix, at feed compound plant	NL
Milk powder skimmed, from drying, at plant	NL
Milk powder whole, consumption mix, at feed compound plant	NL
Milk powder whole, from drying, at plant	NL
Mix of by-products fed to dairy cattle	NL
NPK compound (NPK 15-15-15), at plant	RER
NPK compound (NPK 15-15-15), at regional storehouse	RER
Nitric acid, in water (60% HNO_3) (NPK 13.2-0-0), at plant	RER
Oat grain peeled, consumption mix, at feed compound plant	NL
Oat grain peeled, from dry milling, at plant	BE, NL
Oat grain, at farm	AT, BE, BG, CA, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NL, NO, PL, PT, RO, SE, SK, UA, UK, US
Oat grain, consumption mix, at feed compound plant	IE, NL
Oat grain, dried, at farm	AT, BE, BG, CA, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NL, NO, PL, PT, RO, SE, SK, UA, UK, US
Oat husk meal, consumption mix, at feed compound plant	NL
Oat husk meal, from dry milling, at plant	BE, NL
Oat mill feed meal high grade, consumption mix, at feed compound plant	NL
Oat mill feed meal high grade, mixing final product, at plant	BE, NL
Oat straw, at farm	AT, BE, BG, CA, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NL, NO, PL, PT, RO, SE, SK, UA, UK, US

Oat straw, consumption mix, at feed compound plant	NL
Oil palm fruit bunch, at farm	ID, MY
One-day-chickens, at hatchery	NL
Onion, at farm	FR
PK compound (NPK 0-22-22), at plant	RER
PK compound (NPK 0-22-22), at regional storehouse	RER
Palm kernel expeller, consumption mix, at feed compound plant	NL
Palm kernel expeller, from crushing, at plant	ID, MY
Palm kernels, consumption mix, at feed compound plant	NL
Palm kernels, from crude palm oil production, at plant	ID, MY
Palm oil, consumption mix, at feed compound plant	NL
Pea dry, consumption mix, at feed compound plant	NL
Pea, at farm	AU, CZ, DE, ES, FR, IT, RO, SE, UK
Pea, canned, at plant	RER
Pea, fibres	RER
Pea, hulls (from meal), at plant	RER
Pea, hulls (from protein-concentrate), at plant	RER
Pea, hulls (from protein-isolate), at plant	RER
Pea, meal, at plant	RER
Pea, protein-concentrate, at plant	RER
Pea, protein-isolate, at plant	RER
Pea, slurry (from protein-isolate), at plant	RER
Pea, starch (from protein-concentrate), at plant	RER
Pea, starch (from protein-isolate), at plant	RER
Phosphate rock (32% P2O5, 50% CaO) (NPK 0-32-0)	RER
Phosphoric acid, merchant grade (75% H3PO4) (NPK 0-54-0), at plant	RER
Pig co-product, feed grade, at slaughterhouse	NL
Pig co-product, food grade, at slaughterhouse	NL
Pig co-product, other, at slaughterhouse	NL
Pig feed, fattening pigs	NL

Pig feed, piglets	NL
Pig feed, sows	NL
Pig meat, fresh, at slaughterhouse	NL
Pigeon pea, at farm	IN
Piglets, sow-piglet system, at farm	NL
Pigs to slaughter, pig fattening, at farm	NL
Potassium chloride (NPK 0-0-60), at plant	RER
Potassium chloride (NPK 0-0-60), at regional storehouse	RER
Potassium sulphate (NPK 0-0-50), Mannheim process, at plant	RER
Potassium sulphate (NPK 0-0-50), at regional storehouse	RER
Potato juice concentrated, consumption mix, at feed compound plant	NL
Potato juice concentrated, from wet milling, at plant	DE, NL
Potato protein, consumption mix, at feed compound plant	NL
Potato protein, from wet milling, at plant	DE, NL
Potato pulp pressed fresh+silage, consumption mix, at feed compound plant	NL
Potato pulp pressed fresh+silage, from wet milling, at plant	DE, NL
Potato pulp pressed, consumption mix, at feed compound plant	NL
Potato pulp, dried, consumption mix, at feed compound plant	NL
Potato pulp, from drying, at plant	DE, NL
Potato starch dried, consumption mix, at feed compound plant	NL
Potato starch dried, from wet milling, at plant	DE, NL
Process steam, sulfuric acid production	RER
Rapeseed dried, from drying, at plant	BE, DE, FR, NL, PL, US
Rapeseed expeller, consumption mix, at feed compound plant	NL
Rapeseed expeller, from crushing (pressing), at plant	BE, DE, NL
Rapeseed meal, consumption mix, at feed compound plant	IE, NL
Rapeseed meal, from crushing (solvent), at plant	BE, DE, FR, NL, PL, US
Rapeseed, at farm	AU, BE, BG, CA, CH, CN, CZ, DE, DK, ES, FI, FR, GR, HU, IN, IT, LT, LV, NL, NO, PL, RO, SE, SI, UA, UK, US
Raw milk, at dairy farm	NL

Raw milk, at dairy farm, PEF compliant/NL	IDF
Refined coconut oil, at plant	ID, IN, PH
Refined maize germ oil, (pressing), at plant	DE, FR, NL, US
Refined maize germ oil, (solvent), at plant	DE, FR, NL, US
Refined palm kernel oil, at plant	ID, MY
Refined palm oil, at plant	NL
Refined rapeseed oil, from crushing (pressing), at plant	BE, DE, NL
Refined rapeseed oil, from crushing (solvent), at plant	BE, DE, NL, US
Refined rice bran oil, at plant	CN
Refined soybean oil, from crushing (pressing), at plant	AR, BR, NL
Refined soybean oil, from crushing (solvent), at plant	AR, BR, NL
Refined soybean oil, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL
Refined sunflower oil, from crushing (pressing) at plant	AR, CN, UA
Refined sunflower oil, from crushing (solvent) at plant	AR, CN, UA
Rice bran meal, solvent extracted, consumption mix, at feed compound plant	NL
Rice bran meal, solvent extracted, from rice bran oil production, at plant	CN
Rice bran, from dry milling, at plant	CN
Rice bran, from dry milling, parboiled, at plant	CN
Rice bran, from dry milling, raw, at plant	CN
Rice brokens, from dry milling, at plant	CN
Rice brokens, from dry milling, parboiled, at plant	CN
Rice brokens, from dry milling, raw, at plant	CN
Rice feed meal, consumption mix, at feed compound plant	NL
Rice feed meal, mixing brans and husks, at plant	CN
Rice fibre, protein extraction, at plant	GLO
Rice husk meal, consumption mix, at feed compound plant	NL
Rice husk meal, from dry milling, at plant	CN
Rice husk meal, from dry milling, parboiled, at plant	CN
Rice husk meal, from dry milling, raw, at plant	CN
Rice husk, from dry milling, at plant	CN

Rice husk, from dry milling, parboiled, at plant	CN
Rice husk, from dry milling, raw, at plant	CN
Rice protein, protein extraction, at plant	GLO
Rice starch, protein extraction, at plant	GLO
Rice with hulls, consumption mix, at feed compound plant	NL
Rice without hulls, consumption mix, at feed compound plant	NL
Rice without husks, from dry milling, at plant	CN
Rice without husks, from dry milling, parboiled at plant	CN
Rice without husks, from dry milling, raw, at plant	CN
Rice, at farm	CN
Rice, early, alternate wet and dry, at farm	CN
Rice, early, continuous flooding, at farm	CN
Rice, late, alternate wet and dry, at farm	CN
Rice, late, continuous flooding, at farm	CN
Rice, single, alternate wet and dry, at farm	CN
Rice, single, continuous flooding, at farm	CN
Rye flour, from dry milling, at plant	BE, DE, NL
Rye grain, at farm	AT, BE, BG, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NO, PL, PT, SE, SK, UA
Rye grain, consumption mix, at feed compound plant	NL
Rye grain, dried, at farm	AT, BE, BG, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NO, PL, PT, SE, SK, UA
Rye middlings, consumption mix, at feed compound plant	NL
Rye middlings, from dry milling, at plant	BE, DE, NL
Rye straw, at farm	AT, BE, BG, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NO, PL, PT, SE, SK, UA
Rye straw, consumption mix, at feed compound plant	NL
Single superphosphate, as 35% $Ca(H_2PO_4)_2$ (NPK 0-21-0), at plant	RER
Single superphosphate, as 35% $Ca(H_2PO_4)_2$ (NPK 0-21-0), at regional storehouse	RER
Soap stock (coconut oil refining), at plant	ID, IN, PH
Soap stock (maize germ oil, pressing), at plant	DE, FR, NL, US

Soap stock (maize germ oil, solvent), at plant	DE, FR, NL, US
Soap stock (palm kernel oil refining), at plant	ID, MY
Soap stock (rapeseed pressure crushing), at plant	BE, DE, NL
Soap stock (rapeseed solvent crushing), at plant	BE, DE, NL, US
Soap stock (rice bran oil refining), at plant	CN
Soap stock (soybean pressure crushing), at plant	AR, BR, NL
Soap stock (soybean protein concentrate production), at plant	AR, BR, NL
Soap stock (soybean solvent crushing), at plant	AR, BR, NL
Soap stock (sunflower pressure crushing), at plant	AR, CN, UA
Soap stock (sunflower solvent crushing), at plant	AR, CN, UA
Sodium hydroxide (50% NaOH), production mix	RER
Sodium hydroxide, from amalgam technology (50% NaOH), at plant	RER
Sodium hydroxide, from concentrating diaphragm technology (50% NaOH) at plant	RER
Sodium hydroxide, from concentrating membrane (50% NaOH), at plant	RER
Sodium hydroxide, from diaphragm technology (12% NaOH), at plant	RER
Sodium hydroxide, from membrane technology (33% NaOH), at plant	RER
Sorghum, at farm	AR, AU, IN, MX, US, ZA
Sorghum, consumption mix, at feed compound plant	NL
Sow to slaughter, sow-piglet system, at farm	NL
Soy protein concentrate, consumption mix, at feed compound plant	NL
Soybean expeller, consumption mix, at feed compound plant	NL
Soybean expeller, from crushing (pressing), at plant	AR, BR, NL
Soybean hulls, consumption mix, at feed compound plant	NL
Soybean hulls, from crushing (solvent), at plant	AR, BR, DE, ES, NL, US
Soybean hulls, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL
Soybean lecithin, from crushing (solvent), at plant	DE, ES, NL
Soybean meal, consumption mix, at feed compound plant	NL
Soybean meal, from crushing (solvent), at plant	AR, BR, DE, ES, NL, US
Soybean molasses, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL
Soybean protein concentrate, from crushing (solvent, for protein concentrate), at plant	AR, BR, NL

Soybean, at farm	AR, BR, CA, CN, FR, HU, IN, IT, MX, PL, RO, US
Soybean, consumption mix, at feed compound plant	IE, NL
Soybean, heat treated, consumption mix, at feed compound plant	NL
Soybean, heat treated, from heat treating, at plant	NL
Spinach, at farm	BE, NL
Standardized milk, full, from processing, at plant	NL
Standardized milk, skimmed, from processing, at plant	NL
Starch potato, at farm	AT, BE, BG, CH, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IT, LT, LV, NL, NO, PL, PT, RO, SE
Sugar beet molasses, consumption mix, at feed compound plant	NL
Sugar beet molasses, from sugar production, at Suiker Unie plants	NL
Sugar beet molasses, from sugar production, at plant	DE, FR, PL
Sugar beet pulp, dried, consumption mix, at feed compound plant	NL
Sugar beet pulp, dried, from pulp drying, at Suiker Unie plants	NL
Sugar beet pulp, dried, from pulp drying, at plant	DE
Sugar beet pulp, pressed, from wet pulp pressing, at Suiker Unie plants	NL
Sugar beet pulp, wet, consumption mix, at feed compound plant	NL
Sugar beet pulp, wet, from sugar production, at Suiker Unie plants	NL
Sugar beet pulp, wet, from sugar production, at plant	DE, FR, PL
Sugar beet, at farm	AT, BE, CH, CZ, DE, DK, ES, FI, FR, HU, IT, LT, NL, PL, RO, SE, UA, UK
Sugar beets fresh, consumption mix, at feed compound plant	NL
Sugar cane molasses, consumption mix, at feed compound plant	IE, NL
Sugar cane molasses, from sugar production, at plant	AU, BR, IN, PK, SD, US
Sugar cane, at farm	AR, AU, BR, CN, CO, ID, IN, PH, PK, SD, TH, US, VE
Sugar, from sugar beet, from sugar production, at Suiker Unie plants	NL
Sugar, from sugar beet, from sugar production, at plant	DE, FR, PL
Sugar, from sugar beets, consumption mix, at feed compound plant	NL
Sugar, from sugar cane, from sugar production, at plant	AU, BR, IN, PK, SD, US
Sulfur dioxide, at plant	RER
Sulfuric acid (98% H_2SO_4), at plant	RER

Sunflower seed dehulled, consumption mix, at feed compound plant	NL
Sunflower seed dehulled, from dehulling (full), at plant	AR, CN, UA
Sunflower seed expelled dehulled, consumption mix, at feed compound plant	NL
Sunflower seed expelled dehulled, from crushing (pressing), at plant	AR, CN, UA
Sunflower seed meal, consumption mix, at feed compound plant	NL
Sunflower seed meal, from crushing (solvent), at plant	AR, CN, UA
Sunflower seed partly dehulled, consumption mix, at feed compound plant	NL
Sunflower seed partly dehulled, from dehulling (partial), at plant	AR, CN, UA
Sunflower seed with hulls, consumption mix, at feed compound plant	NL
Sunflower seed, at farm	AR, BG, CN, CZ, ES, FR, GR, HU, IT, RO, UA
Tapioca starch, from processing with use of co-products, at plant	TH
Tapioca starch, from processing without use of co-products, at plant	TH
Tapioca, consumption mix, at feed compound plant	NL
Technical aid, for Meatless, at plant	NL
Transport, airplane, Boeing 747-200F, long	GLO
Transport, airplane, Boeing 747-200F, middle	GLO
Transport, airplane, Boeing 747-200F, short	GLO
Transport, airplane, Boeing 747-400F, long	GLO
Transport, airplane, Boeing 747-400F, middle	GLO
Transport, airplane, Boeing 747-400F, short	GLO
Transport, airplane, Fokker 100, middle	GLO
Transport, airplane, Fokker 100, short	GLO
Transport, barge ship, bulk, 12000t, 100%LF, default	GLO
Transport, barge ship, bulk, 12000t, 100%LF, empty return	GLO
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Transport, barge ship, container, 960t, 80%LF, empty return	GLO
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Transport, freight train, diesel, bulk, 100%LF, flat terrain, empty return	GLO
Transport, freight train, diesel, bulk, 100%LF, hilly terrain, default	GLO
Transport, freight train, diesel, bulk, 100%LF, hilly terrain, empty return	GLO
Transport, freight train, diesel, bulk, 100%LF, mountainous terrain, default	GLO
Transport, freight train, diesel, bulk, 100%LF, mountainous terrain, empty return	GLO
Transport, freight train, diesel, bulk, 50%LF, flat terrain, default	GLO
Transport, freight train, diesel, bulk, 50%LF, flat terrain, empty return	GLO
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Transport, freight train, diesel, container, 100%LF, mountainous terrain, default	GLO
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Transport, freight train, diesel, container, 80%LF, mountainous terrain, default	GLO
Transport, freight train, electricity, bulk, 100%LF, flat terrain, default	GLO
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Transport, freight train, electricity, bulk, 100%LF, hilly terrain, default	GLO
Transport, freight train, electricity, bulk, 100%LF, hilly terrain, empty return	GLO
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Transport, truck 10-20t, EURO1, 100%LF, empty return	GLO
Transport, truck 10-20t, EURO1, 20%LF, default	GLO
Transport, truck 10-20t, EURO1, 20%LF, empty return	GLO
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Transport, truck 10-20t, EURO5, 50%LF, default	GLO
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Transport, truck <10t, EURO2, 50%LF, empty return	GLO
Transport, truck <10t, EURO2, 80%LF, default	GLO
Transport, truck <10t, EURO2, 80%LF, empty return	GLO

Transport, truck <10t, EURO3, 100%LF, default	GLO
Transport, truck <10t, EURO3, 100%LF, empty return	GLO
Transport, truck <10t, EURO3, 20%LF, default	GLO
Transport, truck <10t, EURO3, 20%LF, empty return	GLO
Transport, truck <10t, EURO3, 50%LF, default	GLO
Transport, truck <10t, EURO3, 50%LF, empty return	GLO
Transport, truck <10t, EURO3, 80%LF, default	GLO
Transport, truck <10t, EURO3, 80%LF, empty return	GLO
Transport, truck <10t, EURO4, 100%LF, default	GLO
Transport, truck <10t, EURO4, 100%LF, empty return	GLO
Transport, truck <10t, EURO4, 20%LF, default	GLO
Transport, truck <10t, EURO4, 20%LF, empty return	GLO
Transport, truck <10t, EURO4, 50%LF, default	GLO
Transport, truck <10t, EURO4, 50%LF, empty return	GLO
Transport, truck <10t, EURO4, 80%LF, default	GLO
Transport, truck <10t, EURO4, 80%LF, empty return	GLO
Transport, truck <10t, EURO5, 100%LF, default	GLO
Transport, truck <10t, EURO5, 100%LF, empty return	GLO
Transport, truck <10t, EURO5, 20%LF, default	GLO
Transport, truck <10t, EURO5, 20%LF, empty return	GLO
Transport, truck <10t, EURO5, 50%LF, default	GLO
Transport, truck <10t, EURO5, 50%LF, empty return	GLO
Transport, truck <10t, EURO5, 80%LF, default	GLO
Transport, truck <10t, EURO5, 80%LF, empty return	GLO
Transport, truck >20t, EURO1, 100%LF, default	GLO
Transport, truck >20t, EURO1, 100%LF, empty return	GLO
Transport, truck >20t, EURO1, 20%LF, default	GLO
Transport, truck >20t, EURO1, 20%LF, empty return	GLO
Transport, truck >20t, EURO1, 50%LF, default	GLO
Transport, truck >20t, EURO1, 50%LF, empty return	GLO

Transport, truck >20t, EURO1, 80%LF, default	GLO
Transport, truck >20t, EURO1, 80%LF, empty return	GLO
Transport, truck >20t, EURO2, 100%LF, default	GLO
Transport, truck >20t, EURO2, 100%LF, empty return	GLO
Transport, truck >20t, EURO2, 20%LF, default	GLO
Transport, truck >20t, EURO2, 20%LF, empty return	GLO
Transport, truck >20t, EURO2, 50%LF, default	GLO
Transport, truck >20t, EURO2, 50%LF, empty return	GLO
Transport, truck >20t, EURO2, 80%LF, default	GLO
Transport, truck >20t, EURO2, 80%LF, empty return	GLO
Transport, truck >20t, EURO3, 100%LF, default	GLO
Transport, truck >20t, EURO3, 100%LF, empty return	GLO
Transport, truck >20t, EURO3, 20%LF, default	GLO
Transport, truck >20t, EURO3, 20%LF, empty return	GLO
Transport, truck >20t, EURO3, 50%LF, default	GLO
Transport, truck >20t, EURO3, 50%LF, empty return	GLO
Transport, truck >20t, EURO3, 80%LF, default	GLO
Transport, truck >20t, EURO3, 80%LF, empty return	GLO
Transport, truck >20t, EURO4, 100%LF, default	GLO
Transport, truck >20t, EURO4, 100%LF, empty return	GLO
Transport, truck >20t, EURO4, 20%LF, default	GLO
Transport, truck >20t, EURO4, 20%LF, empty return	GLO
Transport, truck >20t, EURO4, 50%LF, default	GLO
Transport, truck >20t, EURO4, 50%LF, empty return	GLO
Transport, truck >20t, EURO4, 80%LF, default	GLO
Transport, truck >20t, EURO4, 80%LF, empty return	GLO
Transport, truck >20t, EURO5, 100%LF, default	GLO
Transport, truck >20t, EURO5, 100%LF, empty return	GLO
Transport, truck >20t, EURO5, 20%LF, default	GLO
Transport, truck >20t, EURO5, 20%LF, empty return	GLO

Transport, truck >20t, EURO5, 50%LF, default	GLO
Transport, truck >20t, EURO5, 50%LF, empty return	GLO
Transport, truck >20t, EURO5, 80%LF, default	GLO
Transport, truck >20t, EURO5, 80%LF, empty return	GLO
Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at plant	RER
Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at regional storehouse	RER
Triticale, at farm	AT, CH, CZ, DE, ES, FR, HU, LT, LV, NL, PL, PT, RO, SE, SK
Triticale, consumption mix, at feed compound plant	NL
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant	RER
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at regional storehouse	RER
Wheat bran, consumption mix, at feed compound plant	NL
Wheat bran, from dry milling, at plant	BE, DE, NL
Wheat bran, from wet milling, at plant	BE, DE, NL
Wheat feed meal, consumption mix, at feed compound plant	NL
Wheat flour, from dry milling, at plant	BE, DE, NL
Wheat germ, consumption mix, at feed compound plant	NL
Wheat germ, from dry milling, at plant	BE, DE, NL
Wheat gluten feed, consumption mix, at feed compound plant	NL
Wheat gluten feed, from wet milling, at plant	BE, DE, NL
Wheat gluten meal, consumption mix, at feed compound plant	NL
Wheat gluten meal, from wet milling, at plant	BE, DE, NL
Wheat grain, at farm	AR, AT, AU, BE, BG, BR, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IN, IT, LT, LV, MX, NL, NO, PK, PL, PT, RO, SE, UA, UK
Wheat grain, consumption mix, at feed compound plant	IE, NL
Wheat grain, dried, at farm	AR, AT, AU, BE, BG, BR, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IN, IT, LT, LV, MX, NL, NO, PK, PL, PT, RO, SE, UA, UK
Wheat middlings & feed, from dry milling, at plant	BE, DE, NL
Wheat starch slurry, from wet milling, at plant	BE, DE, NL
Wheat starch, dried, consumption mix, at feed compound plant	NL
Wheat starch, from wet milling, at plant	BE, DE, NL

Wheat straw, at farm	AR, AT, AU, BE, BG, BR, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IN, IT, LT, LV, MX, NL, NO, PK, PL, PT, RO, SE, UA, UK
Wheat straw, consumption mix, at feed compound plant	NL
Whey powder, from drying, at plant	NL
White rice, from dry milling, at plant	CN
White rice, from dry milling, parboiled, at plant	CN
White rice, from dry milling, raw, at plant	CN

Appendix C. Economic allocation data

Table C-1: List of the economic allocation data for cultivation and processing of crops (Please note that the van Zeist et al, 2012 reports are background reports of Vellinga et al. 2013)

Process	Price	Unit	Reference
Coconut husk, from dehusking, at plant	0.10	ratio	(van Zeist et al., 2012d)
Coconut, dehusked, from dehusking, at plant	0.90	ratio	van Zeist et al., 2012b)
Coconut copra meal, from crushing, at plant	0.12	$/kg (as is)	van Zeist et al., 2012b)
Crude coconut oil, from crushing, at plant	0.76	$/kg (as is)	van Zeist et al., 2012b)
Palm kernels, from crude palm oil production, at plant	1.36	Malaysia Ringgits/kg (as is)	van Zeist et al., 2012b)
Crude palm oil, from crude palm oil production, at plant	2.35	Malaysia Ringgits/kg (as is)	van Zeist et al., 2012b)
Crude palm kernel oil, from crushing, at plant	2.83	Malaysia Ringgits/kg (as is)	van Zeist et al., 2012b)
Palm kernel expeller, from crushing, at plant	0.28	Malaysia Ringgits/kg (as is)	van Zeist et al., 2012b)
Rapeseed meal, from crushing (solvent), at plant	0.21	$/kg (as is)	van Zeist et al., 2012b)
Crude rapeseed oil, from crushing (solvent), at plant	0.99	$/kg (as is)	van Zeist et al., 2012b)
Rapeseed expeller, from crushing (pressing), at plant	0.21	$/kg (as is)	van Zeist et al., 2012b)
Crude rapeseed oil, from crushing (pressing), at plant	0.99	$/kg (as is)	van Zeist et al., 2012b)
Crude soybean oil, from crushing (solvent), at plant	0.69	$/kg (as is)	van Zeist et al., 2012b)
Soybean hulls, from crushing (solvent), at plant	0.13	$/kg (as is)	van Zeist et al., 2012b)
Soybean meal, from crushing (solvent), at plant	0.25	$/kg (as is)	van Zeist et al., 2012b)
Crude soybean oil, from crushing (pressing), at plant	0.69	$/kg (as is)	van Zeist et al., 2012b)
Soybean expeller, from crushing (pressing), at plant	0.23	$/kg (as is)	van Zeist et al., 2012b)
Crude soybean oil, from crushing (solvent), at plant	0.69	$/kg (as is)	van Zeist et al., 2012b)
Soybean hulls, from crushing (solvent), at plant	0.13	$/kg (as is)	van Zeist et al., 2012b)
Soybean meal, from crushing (solvent), at plant	0.25	$/kg (as is)	van Zeist et al., 2012b)
Crude sunflower oil, from crushing (solvent), at plant	1.02	$/kg (as is)	van Zeist et al., 2012b)
Sunflower seed meal, from crushing (solvent), at plant	0.21	$/kg (as is)	van Zeist et al., 2012b)
Crude sunflower oil, from crushing (pressing), at plant	1.02	$/kg (as is)	van Zeist et al., 2012b)

Sunflower seed expelled dehulled, from crushing (pressing), at plant	0.21	$/kg (as is)	van Zeist et al., 2012b)
Oat grain peeled, from dry milling, at plant	0.30	€/kg (as is)	(van Zeist et al., 2012b)
Oat husk meal, from dry milling, at plant	0.10	€/kg (as is)	(van Zeist et al., 2012b)
Rice husk meal, from dry milling, at plant	0.04	€/kg (as is)	(van Zeist et al., 2012b)
Rice without husks, from dry milling, at plant	0.61	€/kg (as is)	(van Zeist et al., 2012b)
Rice bran, from dry milling, at plant	0.20	€/kg (as is)	(van Zeist et al., 2012b)
Rice husk, from dry milling, at plant	0.04	€/kg (as is)	(van Zeist et al., 2012b)
White rice, from dry milling, at plant	0.83	€/kg (as is)	(van Zeist et al., 2012b)
Crude rice bran oil, from rice bran oil production, at plant	0.85	€/kg (as is)	(van Zeist et al., 2012b)
Rice bran meal, solvent extracted, from rice bran oil production, at plant	0.10	€/kg (as is)	(van Zeist et al., 2012b)
Rye flour, from dry milling, at plant	0.43	€/kg (as is)	(van Zeist et al., 2012b)
Rye middlings, from dry milling, at plant	0.30	€/kg (as is)	(van Zeist et al., 2012b)
Wheat germ, from dry milling, at plant	0.38	€/kg (as is)	(van Zeist et al., 2012b)
Wheat middlings & feed, from dry milling, at plant	0.12	€/kg (as is)	(van Zeist et al., 2012b)
Wheat bran, from dry milling, at plant	0.13	€/kg (as is)	(van Zeist et al., 2012b)
Wheat flour, from dry milling, at plant	0.27	€/kg (as is)	(van Zeist et al., 2012b)
Maize flour, from dry milling, at plant	0.60	€/kg (as is)	(van Zeist et al., 2012b)
Maize middlings, from dry milling, at plant	0.20	€/kg (as is)	(van Zeist et al., 2012b)
Food grade fat, from fat melting, at plant	0.87	€/kg (as is)	(van Zeist et al., 2012a)
Greaves meal, from fat melting, at plant	0.21	€/kg (as is)	(van Zeist et al., 2012a)
Cream, full, from processing, at plant	1.31	€/kg (as is)	(van Zeist et al., 2012a)
Standardized milk, full, from processing, at plant	0.48	€/kg (as is)	(van Zeist et al., 2012a)
Cream, skimmed, from processing, at plant	1.31	€/kg (as is)	(van Zeist et al., 2012a)
Standardized milk, skimmed, from processing, at plant	0.48	€/kg (as is)	(van Zeist et al., 2012a)
Soybean protein concentrate, from crushing (solvent, for protein concentrate), at plant	1.60	$/kg (as is)	(van Zeist et al., 2012c)
Soybean hulls, from crushing (solvent, for protein concentrate), at plant	0.18	$/kg (as is)	(van Zeist et al., 2012c)
Soybean molasses, from crushing (solvent, for protein concentrate), at plant	1.34	$/kg (as is)	(van Zeist et al., 2012c)
Crude soybean oil, from crushing (solvent, for protein concentrate), at plant	0.51	$/kg (as is)	(van Zeist et al., 2012c)

Lime fertilizer, from sugar production, at plant	0.10	€/kg (as is)	(van Zeist et al., 2012f)
Sugar, from sugar beet, from sugar production, at plant	0.83	€/kg (as is)	(van Zeist et al., 2012f)
Sugar beet pulp, wet, from sugar production, at plant	0.00	€/kg (as is)	(van Zeist et al., 2012f)
Sugar beet molasses, from sugar production, at plant	0.18	€/kg (as is)	(van Zeist et al., 2012f)
Sugar cane molasses, from sugar production, at plant	0.14	€/kg (as is)	(van Zeist et al., 2012f)
Sugar, from sugar cane, from sugar production, at plant	0.68	€/kg (as is)	(van Zeist et al., 2012f)
Maize, steeped , from wet milling (receiving and steeping), at plant	0.37	€/kg (as is)	(van Zeist et al., 2012e)
Maize steepwater, wet, from wet milling (receiving and steeping), at plant	0.18	€/kg (as is)	(van Zeist et al., 2012e)
Crude maize germ oil, from wet milling (germ oil production, pressing), at plant	0.91	€/kg (as is)	(van Zeist et al., 2012e)
Maize germ meal expeller, from wet milling (germ oil production, pressing), at plant	0.11	€/kg (as is)	(van Zeist et al., 2012e)
Crude maize germ oil, from wet milling (germ oil production, solvent), at plant	0.91	€/kg (as is)	(van Zeist et al., 2012e)
Maize germ meal extracted, from wet milling (germ oil production, solvent), at plant	0.11	€/kg (as is)	(van Zeist et al., 2012e)
Maize germ, wet, from wet milling (degermination), at plant	0.63	€/kg (as is)	(van Zeist et al., 2012e)
Maize degermed, from wet milling (degermination), at plant	0.35	€/kg (as is)	(van Zeist et al., 2012e)
Maize fibre/bran, wet, from wet milling (grinding and screening), at plant	0.21	€/kg (as is)	(van Zeist et al., 2012e)
Maize starch and gluten slurry, from wet milling (grinding and screening), at plant	0.37	€/kg (as is)	(van Zeist et al., 2012e)
Maize gluten, wet, from wet milling (gluten recovery), at plant	0.52	€/kg (as is)	(van Zeist et al., 2012e)
Maize starch, wet, from wet milling (gluten recovery), at plant	0.39	€/kg (as is)	(van Zeist et al., 2012e)
Potato juice concentrated, from wet milling, at plant	0.50	ratio	(van Zeist et al., 2012e)
Potato protein, from wet milling, at plant	20.00	ratio	(van Zeist et al., 2012e)
Potato protein, from wet milling, at plant	20.00	ratio	(van Zeist et al., 2012e)
Potato pulp pressed fresh+silage, from wet milling, at plant	0.35	ratio	(van Zeist et al., 2012e)
Potato starch dried, from wet milling, at plant	10.00	ratio	(van Zeist et al., 2012e)
Wheat bran, from wet milling, at plant	0.12	€/kg (as is)	(van Zeist et al., 2012e)
Wheat gluten feed, from wet milling, at plant	0.16	€/kg (as is)	(van Zeist et al., 2012e)
Wheat gluten meal , from wet milling, at plant	0.78	€/kg (as is)	(van Zeist et al., 2012e)
Wheat starch, from wet milling, at plant	0.25	€/kg (as is)	(van Zeist et al., 2012e)
Wheat starch slurry, from wet milling, at plant	0.02	€/kg (as is)	(van Zeist et al., 2012e)

Barley grain, at farm BE	0.12	€/kg (as is)	(Marinussen et al., 2012a)
Barley straw, at farm BE	0.05	€/kg (as is)	(Marinussen et al., 2012a)
Barley grain, at farm DE	0.16	€/kg (as is)	(Marinussen et al., 2012a)
Barley straw, at farm DE	0.08	€/kg (as is)	(Marinussen et al., 2012a)
Barley grain, at farm FR	0.12	€/kg (as is)	(Marinussen et al., 2012a)
Barley straw, at farm FR	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Oat grain, at farm BE	0.10	€/kg (as is)	(Marinussen et al., 2012a)
Oat straw, at farm BE	0.05	€/kg (as is)	(Marinussen et al., 2012a)
Oat grain, at farm NL	0.13	€/kg (as is)	(Marinussen et al., 2012a)
Oat straw, at farm NL	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Rye grain, at farm DE	0.10	€/kg (as is)	(Marinussen et al., 2012a)
Rye straw, at farm DE	0.05	€/kg (as is)	(Marinussen et al., 2012a)
Rye straw, at farm PL	0.10	€/kg (as is)	(Marinussen et al., 2012a)
Rye straw, at farm PL	0.05	€/kg (as is)	(Marinussen et al., 2012a)
Wheat grain, at farm DE	0.14	€/kg (as is)	(Marinussen et al., 2012a)
Wheat straw, at farm DE	0.07	€/kg (as is)	(Marinussen et al., 2012a)
Wheat grain, at farm FR	0.13	€/kg (as is)	(Marinussen et al., 2012a)
Wheat straw, at farm FR	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Wheat grain, at farm NL	0.13	€/kg (as is)	(Marinussen et al., 2012a)
Wheat straw, at farm NL	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Wheat grain, at farm UK	0.13	€/kg (as is)	(Marinussen et al., 2012a)
Wheat straw, at farm UK	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Barley grain, at farm IE	0.14	€/kg (as is)	(Marinussen et al., 2012a)
Barley straw, at farm IE	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Barley grain, at farm UK	0.14	€/kg (as is)	(Marinussen et al., 2012a)
Barley straw, at farm UK	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Wheat grain, at farm IE	0.13	€/kg (as is)	(Marinussen et al., 2012a)
Wheat straw, at farm IE	0.06	€/kg (as is)	(Marinussen et al., 2012a)

Oat grain, at farm US	0.12	€/kg (as is)	(Marinussen et al., 2012a)
Oat straw, at farm US	0.06	€/kg (as is)	(Marinussen et al., 2012a)
Broad bean, meal, at plant	0.55	€/kg (as is)	(Broekema, 2011)
Broad bean, hulls, at plant	0.13	€/kg (as is)	(Broekema, 2011)
Lupine, meal, at plant	2.50	ratio	(Broekema, 2011)
Lupine, hulls, at plant	0.75	ratio	(Broekema, 2011)
Pea, meal, at plant	0.45	€/kg (as is)	(Broekema, 2011)
Pea, hulls (from meal), at plant	0.27	€/kg (as is)	(Broekema, 2011)
Pea, hulls (from protein-concentrate), at plant	0.21	€/kg (as is)	(Broekema, 2011)
Pea, hulls (from protein-isolate), at plant	0.21	€/kg (as is)	(Broekema, 2011)
Pea, protein-concentrate, at plant	1.80	€/kg (as is)	(Broekema, 2011)
Pea, starch (from protein-concentrate), at plant	0.13	€/kg (as is)	(Broekema, 2011)
Pea, starch (from protein-isolate), at plant	0.60	€/kg (as is)	(Broekema, 2011)
Pea, protein-isolate, at plant	2.80	€/kg (as is)	(Broekema, 2011)
Pea, slurry, at plant	0	€/kg (as is)	(Broekema, 2011)

Appendix D. Transport distances table

Table D-1: Transport distances (in km) and transport mode split for crops and processed crop products.

Country A	Country B	Base Product	Transport Moment	Lorry dist	Train dist	InlandShip dist	SeaShip dist
AR	AR	Soybean	Crop_to_Process	205	40	5	0
AR	AR	Sunflower seed	Crop_to_Process	410	80	10	0
AR	NL	Sorghum	Crop_to_Mix	466	82	29	11738
AR	NL	Soybean	Crop_to_Process	410	80	10	11738
AR	NL	Soybean	Crop_to_Mix	466	82	29	11738
AR	NL	Soybean	Process_to_Mix	56	2	19	11738
AR	NL	Sunflower seed	Process_to_Mix	56	2	19	11738
AR	NL	Sunflower seed	Crop_to_Mix	466	82	29	11738
AU	AU	Sugar cane	Crop_to_Process	25	0	0.0	0
AU	NL	Lupine	Crop_to_Mix	456	102	19	17826
AU	NL	Pea	Crop_to_Mix	0	102	19	17826
AU	NL	Sugar cane	Process_to_Mix	456	102	19	21812
BE	BE	Barley	Crop_to_Process	59	7	11	0
BE	BE	Oat	Crop_to_Process	59	7	11	0
BE	NL	Barley	Crop_to_Mix	187	49	135	0
BE	NL	Barley	Process_to_Mix	128	42	123	0
BE	NL	Oat	Crop_to_Mix	187	49	135	0
BE	NL	Oat	Crop_to_Process	131	46	116	0
BE	NL	Oat	Process_to_Mix	128	42	123	0
BE	NL	Rapeseed	Process_to_Mix	128	42	123	0
BE	NL	Rye	Process_to_Mix	128	42	123	0

Country A	Country B	Base Product	Transport Moment	Lorry dist	Train dist	InlandShip dist	SeaShip dist
BE	NL	Wheat	Process_to_Mix	128	42	123	0
BR	BR	Soybean	Crop_to_Process	867	477	101	0
BR	BR	Sugar cane	Crop_to_Process	25	0	0.0	0
BR	IE	Soybean	Crop_to_Mix	925	477	101	9300
BR	NL	Citrus	Process_to_Mix	56	2	19	9684
BR	NL	Maize	Crop_to_Mix	923	479	120	9684
BR	NL	Soybean	Crop_to_Process	867	476.85	101.15	9684
BR	NL	Soybean	Crop_to_Mix	923	479	120	9684
BR	NL	Soybean	Process_to_Mix	56	2	19	9684
BR	NL	Sugar cane	Process_to_Mix	923	479	120	9684
CN	CN	Rice	Crop_to_Process	455	1005	136	455
CN	CN	Sunflower seed	Crop_to_Process	455	1005	136	455
CN	NL	Rice	Crop_to_Mix	510	1007	156	19568
CN	NL	Rice	Process_to_Mix	56	2	19	19113
CN	NL	Sunflower seed	Process_to_Mix	56	2	19	19113
CN	NL	Sunflower seed	Crop_to_Mix	510	1007	156	19568
DE	BE	Rapeseed	Crop_to_Process	269	134	181	0
DE	BE	Rye	Crop_to_Process	269	134	181	0
DE	BE	Wheat	Crop_to_Process	269	134	181	0
DE	DE	Barley	Crop_to_Process	84	18	4	0
DE	DE	Maize	Crop_to_Process	84	18	4	0
DE	DE	Rapeseed	Crop_to_Process	84	18	4	0
DE	DE	Rye	Crop_to_Process	84	18	4	0
DE	DE	Starch potato	Crop_to_Process	84	18	4	0
DE	DE	Sugar beet	Crop_to_Process	84	18	4	0
DE	DE	Wheat	Crop_to_Process	84	18	4	0
DE	NL	Barley	Crop_to_Mix	301	121	177	0
DE	NL	Barley	Process_to_Mix	216	103	174	0

Country A	Country B	Base Product	Transport Moment	Lorry dist	Train dist	InlandShip dist	SeaShip dist
DE	NL	Lupine	Crop_to_Mix	301	121	177	0
DE	NL	Maize	Crop_to_Mix	301	121	177	0
DE	NL	Maize	Crop_to_Process	245	119	158	0
DE	NL	Maize	Process_to_Mix	216	103	174	0
DE	NL	Pea	Crop_to_Mix	301	121	177	0
DE	NL	Rapeseed	Crop_to_Process	245	119	158	0
DE	NL	Rapeseed	Process_to_Mix	216	103	174	0
DE	NL	Rye	Crop_to_Mix	301	121	177	0
DE	NL	Rye	Crop_to_Process	245	119	158	0
DE	NL	Rye	Process_to_Mix	216	103	174	0
DE	NL	Starch potato	Process_to_Mix	216	103	174	0
DE	NL	Sugar beet	Process_to_Mix	216	103	174	0
DE	NL	Triticale	Crop_to_Mix	301	121	177	0
DE	NL	Wheat	Crop_to_Mix	301	121	177	0
DE	NL	Wheat	Crop_to_Process	245	119	158	0
DE	NL	Wheat	Process_to_Mix	216	103	174	0
FR	BE	Rapeseed	Crop_to_Process	368	139	146	0
FR	BE	Wheat	Crop_to_Process	368	139	146	0
FR	DE	Maize	Crop_to_Process	551	215	252	0
FR	FR	Barley	Crop_to_Process	80	11	2	0
FR	FR	Maize	Crop_to_Process	80	11	2	0
FR	NL	Barley	Crop_to_Mix	274	75	90	498
FR	NL	Barley	Process_to_Mix	194	63	88	498
FR	NL	Maize	Crop_to_Mix	274	75	90	498
FR	NL	Maize	Crop_to_Process	218	73	71	498
FR	NL	Maize	Process_to_Mix	194	63	88	498
FR	NL	Pea	Crop_to_Mix	274	75	90	498
FR	NL	Rapeseed	Crop_to_Process	194	63	88	498

Country A	Country B	Base Product	Transport Moment	Lorry dist	Train dist	InlandShip dist	SeaShip dist
FR	NL	Sunflower seed	Crop_to_Mix	274	75	90	498
FR	NL	Triticale	Crop_to_Mix	274	75	90	498
FR	NL	Wheat	Crop_to_Mix	274	75	90	498
FR	NL	Wheat	Crop_to_Process	218	73	71	498
ID	ID	Coconut	Crop_to_Process	15	0	0.0	0
ID	ID	Oil palm fruit bunch	Crop_to_Process	15	0	0.0	0
ID	NL	Coconut	Process_to_Mix	456	2	19	15794
ID	NL	Oil palm fruit bunch	Process_to_Mix	456	2	19	15794
IE	IE	Barley	Crop_to_Mix	58	1	0.0	0
IE	IE	Barley	Crop_to_Process	58	1	0.0	0
IE	IE	Barley	Process_to_Mix	58	1	0.0	0
IE	IE	Wheat	Crop_to_Mix	58	1	0.0	0
IN	IE	Sugar cane	Process_to_Mix	58	1	0.0	11655
IN	IN	Coconut	Crop_to_Process	15	0	0.0	0
IN	IN	Sugar cane	Crop_to_Process	25	0	0.0	0
IN	NL	Coconut	Process_to_Mix	224	672	19	11655
IN	NL	Sugar cane	Process_to_Mix	224	2	19	11655
MY	MY	Oil palm fruit bunch	Crop_to_Process	15	0	0.0	0
MY	NL	Oil palm fruit bunch	Process_to_Mix	160	107	19	14975
NL	BE	Oat	Crop_to_Process	141	26	128	0
NL	BE	Wheat	Crop_to_Process	141	26	128	0
NL	NL	Animal by-product	Process_to_Mix	56	2	19	0
NL	NL	Brewers grains	Process_to_Mix	56	2	19	0
NL	NL	Fodder beet	Crop_to_Mix	56	2	19	0
NL	NL	Fodder beet	Crop_to_Process	56	2	19	0
NL	NL	Fodder beet	Process_to_Mix	56	2	19	0
NL	NL	Maize	Process_to_Mix	56	2	19	0
NL	NL	Milk	Crop_to_Process	93	0	0	0

Country A	Country B	Base Product	Transport Moment	Lorry dist	Train dist	InlandShip dist	SeaShip dist
NL	NL	Milk	Process_to_Mix	56	2	19	0
NL	NL	Oat	Process_to_Mix	56	2	19	0
NL	NL	Oat	Crop_to_Process	56	2	19	0
NL	NL	Oat	Crop_to_Mix	56	2	19	0
NL	NL	Rapeseed	Process_to_Mix	56	2	19	0
NL	NL	Rye	Process_to_Mix	56	2	19	0
NL	NL	Soybean	Process_to_Mix	56	2	19	0
NL	NL	Starch potato	Crop_to_Process	56	2	19	0
NL	NL	Starch potato	Process_to_Mix	56	2	19	0
NL	NL	Sugar beet	Crop_to_Process	56	2	19	0
NL	NL	Sugar beet	Process_to_Mix	56	2	19	0
NL	NL	Sugar beet	Crop_to_Mix	56	2	19	0
NL	NL	Triticale	Crop_to_Mix	56	2	19	0
NL	NL	Wheat	Crop_to_Mix	56	2	19	0
NL	NL	Wheat	Process_to_Mix	56	2	19	0
NL	NL	Wheat	Crop_to_Process	56	2	19	0
PH	NL	Coconut	Process_to_Mix	456	2	19	17811
PH	PH	Coconut	Crop_to_Process	15	0	0.0	0
PK	IE	Sugar cane	Process_to_Mix	58	1	0.0	10900
PK	NL	Sugar cane	Process_to_Mix	1075	2	19	11275
PK	PK	Sugar cane	Crop_to_Process	25	0	0.0	0
PL	BE	Rye	Crop_to_Process	697	305	12	230
PL	NL	Rye	Crop_to_Mix	689	280	30	207
PL	NL	Rye	Crop_to_Process	633	278	10	207
SD	NL	Sugar cane	Process_to_Mix	461	2	19	7439
SD	SD	Sugar cane	Crop_to_Process	25	0	0.0	0
TH	NL	Cassava	Process_to_Mix	363	2	19	16787
TH	TH	Cassava	Crop_to_Process	15	0	0.0	0

Country A	Country B	Base Product	Transport Moment	Lorry dist	Train dist	InlandShip dist	SeaShip dist
UA	NL	Sunflower seed	Process_to_Mix	56	2	19	6423
UA	NL	Sunflower seed	Crop_to_Mix	341	2	19	6423
UA	UA	Sunflower seed	Crop_to_Process	285	0	0.0	0
UK	BE	Wheat	Crop_to_Process	134	11	0.09	784
UK	IE	Barley	Crop_to_Mix	170	12	0.1	441
UK	IE	Barley	Process_to_Mix	86	1	0.0	441
UK	IE	Wheat	Crop_to_Mix	170	12	0.1	441
UK	NL	Wheat	Crop_to_Mix	183	14	19	684
UK	NL	Wheat	Crop_to_Process	128	11	0.1	684
UK	UK	Barley	Crop_to_Process	84	11	0.1	0
US	DE	Maize	Crop_to_Process	182	619	1019	7266
US	IE	Maize	Crop_to_Mix	240	619	1019	5700
US	IE	Oat	Crop_to_Mix	240	619	1019	5700
US	IE	Rapeseed	Process_to_Mix	58	1	0.0	5700
US	NL	Citrus	Process_to_Mix	56	2	19	6423
US	NL	Maize	Crop_to_Mix	238	621	1038	6365
US	NL	Maize	Crop_to_Process	182	619	1019	6365
US	NL	Maize	Crop_to_Mix	238	621	1038	6365
US	NL	Maize	Process_to_Mix	56	2	19	6365
US	NL	Sorghum	Crop_to_Mix	238	621	1038	6365
US	NL	Soybean	Crop_to_Process	182	619	1019	6365
US	NL	Soybean	Process_to_Mix	56	2	19	6365
US	NL	Soybean	Crop_to_Mix	238	621	1038	6365
US	NL	Sugar cane	Process_to_Mix	238	2	19	6365
US	US	Maize	Crop_to_Process	182	619	1019	0
US	US	Rapeseed	Crop_to_Process	182	619	1019	0
US	US	Sugar cane	Crop_to_Process	25	0	0.0	0

Appendix E. Water use data of US crops

Table E-1:: Comparison of irrigation water use in LCA commons dataset and Water footprint network data ("Blue water")

FAO Item Name	State	Average Yield (kg/ha)	Water use m3/ton	Water use/WFP data m3/ton	Absolute difference
Maize	Colorado	7738	326	355	29
Maize	Kansas	8047	165	265	100
Maize	Texas	6306	343	254	89
Maize	Nebraska	8522	203	191	13
Maize	Georgia	6913	102	71	31
Maize	Missouri	7296	29	27	2
Maize	North Dakota	6333	0	23	23
Maize	South Dakota	6208	4	17	13
Maize	Michigan	6475	11	14	3
Maize	South Carolina	4711	0	11	11
Maize	Indiana	8468	0	7	7
Maize	Illinois	8771	1	5	4
Maize	Minnesota	8384	1	4	3
Maize	North Carolina	5595	0	4	4
Maize	Wisconsin	6508	1	3	2
Maize	Kentucky	7176	0	2	2
Maize	Iowa	9045	0	2	2
Maize	New York	3302	0	1	1
Maize	Pennsylvania	5058	0	1	1
Maize	Ohio	7906	0	0	0
Cottonseed	Arizona	1370	33409	7621	25787
Cottonseed	California	1338	19905	4584	15322
Cottonseed	Arkansas	894	1373	2946	1573
Cottonseed	Texas	469	1259	2744	1485
Cottonseed	Missouri	878	866	1680	814
Cottonseed	Mississippi	883	407	1481	1073
Cottonseed	Louisiana	814	378	1106	727
Cottonseed	Georgia	714	835	487	348
Cottonseed	Alabama	607	76	127	52
Cottonseed	South Carolina	699	36	90	54
Cottonseed	Tennessee	681	0	59	59
Cottonseed	North Carolina	717	0	19	19
Wheat	Montana	1971	0	53	53
Wheat	North Dakota	1851	0	1	1
Oats	Michigan	1823	0	172	172
Oats	New York	1529	0	78	78
Oats	Wisconsin	1234	0	75	75
Oats	Nebraska	1047	514	62	452

Oats	Pennsylvania	1550	0	24	24
Oats	Minnesota	1471	0	20	20
Oats	Kansas	846	0	12	12
Oats	South Dakota	1223	0	5	5
Oats	North Dakota	1036	0	1	1
Groundnuts, with shell	Texas	3233	1039	694	345
Groundnuts, with shell	Georgia	3094	240	150	90
Groundnuts, with shell	Florida	2814	0	93	93
Groundnuts, with shell	Alabama	2768	12	26	14
Groundnuts, with shell	North Carolina	3233	0	12	12
Rice, paddy	California	8532	1503	1368	136
Rice, paddy	Arkansas	7698	798	804	5
Rice, paddy	Mississippi	7805	1141	750	391
Rice, paddy	Texas	8040	911	740	170
Rice, paddy	Missouri	7107	929	655	274
Rice, paddy	Louisiana	6499	899	613	286
Soybeans	Arkansas	1951	419	670	252
Soybeans	Nebraska	2827	316	431	114
Soybeans	Mississippi	1760	303	315	12
Soybeans	Kansas	1818	162	206	45
Soybeans	Louisiana	1798	88	83	5
Soybeans	Missouri	2279	18	70	52
Soybeans	Michigan	2652	5	38	33
Soybeans	South Dakota	2304	0	34	34
Soybeans	Maryland	1484	0	21	21
Soybeans	Wisconsin	2828	0	16	16
Soybeans	Indiana	2861	0	13	13
Soybeans	Illinois	2911	2	11	9
Soybeans	Minnesota	2754	3	11	8
Soybeans	North Dakota	2127	0	9	9
Soybeans	Tennessee	1962	0	9	9
Soybeans	Virginia	1757	0	9	9
Soybeans	Kentucky	2238	0	5	5
Soybeans	Iowa	3101	0	4	4
Soybeans	North Carolina	1801	0	3	3
Soybeans	Pennsylvania	2152	0	1	1
Soybeans	Ohio	2669	0	0	0
Wheat	Idaho	5056	436	864	428
Wheat	Oregon	3251	1508	275	1234
Wheat	Washington	3109	141	262	121
Wheat	Montana	1825	22	53	31
Wheat	South Dakota	2382	0	3	3

Wheat	North Dakota	2267	0	1	1
Wheat	Minnesota	2883	0	0	0
Wheat	Idaho	5307	205	864	659
Wheat	Texas	1027	230	304	74
Wheat	Oregon	4207	67	275	208
Wheat	Washington	4346	46	262	216
Wheat	Colorado	1975	61	239	178
Wheat	Nebraska	2479	13	115	102
Wheat	Kansas	2437	18	76	58
Wheat	Montana	2218	0	53	53
Wheat	Oklahoma	1493	0	36	36
Wheat	Georgia	2393	0	23	23
Wheat	Delaware	3475	0	22	22
Wheat	Arkansas	3385	0	19	19
Wheat	Mississippi	2837	0	11	11
Wheat	Ohio	4317	0	10	10
Wheat	Missouri	3099	0	6	6
Wheat	North Carolina	2540	0	5	5
Wheat	Kentucky	2403	0	4	4
Wheat	Michigan	4186	0	3	3
Wheat	South Dakota	2220	0	3	3
Wheat	North Dakota	3033	0	1	1
Wheat	Illinois	3619	0	1	1
Wheat	Pennsylvania	3400	0	0	0
Wheat	Minnesota	2084	0	0	0

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 5,000 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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