World Food LCA Database

Documentation

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Appendix
Main input data including references, data levels, data quality rating, background parameters, as well as the complete list of datasets and sub-datasets included in WFLDB 3.9 are provided in the Excel files:
WFLDB-3.9_Documentation_Appendix-1_DQR&MainInputs_20231023.xlsx

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Abbreviations

a.i.	Active ingredient in chemical products, typically in pesticides
BMR	Ratio between the mass of meat and the mass of milk produced
CH_4	Methane
EFPRA	European Fat Processors and Renderers Association
FAO	Food and Agriculture Organisation of the United Nations
FPCM	Fat and protein corrected milk
ha	Hectare
HAC	High activity clay
ICID	International Commission on Irrigation & Drainage
IDF	International Dairy Federation
IFA	International Fertiliser Association
INRA	Institut National de la Recherche Agronomique
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
K	Potassium (kg K_2O)
kg	Kilogram
LAC	Low activity clay
LUC	Land use change
m^3	Cubic meter
N	Nitrogen (kg N)
N_2O	Nitrous oxide
NFC	Not from concentrate (for juices)
NH_3	Ammonia
NO_3^-	Nitrate
P	Phosphorous (kg P_2O_5)
PEFCR	Product Environmental Footprint Category Rules
SALCA	Swiss Agricultural Life Cycle Assessment
SOC	Soil organic carbon
VEG	Vegetation
WFLDB	World Food LCA Database

1 Fertilisers production

1.1 Data and technology

Inventory data on the production of fertilisers and their precursors have been modelled based on primary data collected from Fertilisers Europe for the year 2011. These datasets have been complemented with ecoinvent for minor inputs such as infrastructure, chemical inputs, etc. Tab. 1 presents the datasets of fertilisers and their precursors developed for WFLDB as well as their description.

Tab. 1: Fertilisers and precursors datasets modelled in WFLDB

Fertiliser	Datasets	Process description
Ammonia	• Ammonia, steam reforming, at plant	State-of-the-art technology used in European ammonia production plants. The most efficient and simplest way of ammonia synthesis gas production is natural gas reforming with steam and air. In the modelled process, a steam reforming production process based on natural gas is presented because about 85 % of the world ammonia production is using the steam reforming process. The ammonia production process can be divided into several steps: desulfurization, primary production, secondary reforming, shift conversion, CO_2 removal, methanation, synthesis gas compression and ammonia synthesis. It is assumed, that all carbon dioxide is emitted without any use - except if the ammonia is used for the urea or urea ammonium nitrate production. In these cases, it is state-of-the-art that the carbon dioxide originating from the ammonia production is directly used for the urea and urea ammonium nitrate production as input.
Ammonium nitrate (33.5% N)	• Ammonium nitrate (AN, 33.5 % N), at plant • Ammonium nitrate (AN), as N, at plant	State-of-the-art technology used in European ammonium nitrate production plants. Ammonium nitrate is a nitrogenous fertiliser with different N contents. In the modelled case, a N content of 33.5 % is assumed. It is produced by the neutralization of aqueous nitric acid by gaseous ammonia. The production process basically comprises three main unit operations: 1. neutralisation, 2. evaporation, 3. solidification (prilling and granulation). The energy utilisation has improved extensively through the introduction of pressure neutralisers with recycling and heat recovery. The neutralization reaction as the first process step is strongly exothermic. In the second step, the evaporation, a solution is formed at a high concentration and the excess water is evaporated. The last step, the solidification, makes the ammonium nitrate into prills or granules.
Ammonium nitrate phosphate (ANP) (22% N, 22% P2O5)	• Ammonium nitrate phosphate (ANP) (22 % N, 22% P2O5), at plant • Ammonium nitrate phosphate (ANP), as N, at plant • Ammonium nitrate phosphate (ANP), as P2O5, at plant	Dataset adapted from the ecoinvent processes "Nitrogen fertiliser, as N {RER}| ammonium nitrate phosphate production | Alloc Rec, U" and "Phosphate fertiliser, as P2O5 {RER}| ammonium nitrate phosphate production | Alloc Rec, U". The quantity of % N and P2O5 as well as the amount of ammonia and nitric acid are taken from Patyk & Reinhardt (1997).
Ammonium phosphate (52% P_2O_5 8.4% N),	• Monoammonium phosphate (52% P_2O_5, 8.4% N), at plant • Monoammonium phosphate (MAP), as N, at plant • Monoammonium phosphate (MAP), as P_2O_5, at plant	Ammonium phosphate is an intermediate used to produce complex fertilisers. It has a P_2O_5 content of 52 % and an N content of 8.4 %. In order to produce ammonium phosphate, nitric acid attack of phosphate rock is used instead of sulfuric acid. Thus ammonia, phosphate rock and energy are used to produce ammonium phosphate.

Fertiliser	Datasets	Process description
Calcium ammonium nitrate (27% N)	• Calcium ammonium nitrate (27% N), at plant • Calcium ammonium nitrate (CAN), as N, at plant	Calcium ammonium nitrate is a fertiliser with 26 - 27 % N content. In the modelled case, an N content of 27 % is assumed. It is produced by neutralising nitric acid with ammonia. This is an exothermic process, producing ammonium nitrate solution and steam. The ammonium nitrate is then mixed with a filler that contains dolomite or lime to produce calcium ammonium nitrate. The final product is either prilled or granulated. The process steps are neutralisation, evaporation and solidification. This dataset includes the mining process of dolomite. Transport of the dolomite, nitric acid and ammonia to the calcium ammonium nitrate plant is included with the respective fuel demand and assumed by tanker and train.
Diammonium phosphate (18% N 46% P_2O_5)	• Diammonium phosphate (18% N 46% P_2O_5), at plant • Diammonium phosphate (DAP), as N, at plant • Diammonium phosphate (DAP), as P_2O_5, at plant	DAP is a fertiliser containing 18% N and 46% P_2O_5. For the production of diammonium phosphate, phosphoric acid is neutralized with gaseous ammonia. This process has gone through the development phases from atmospheric neutralisation in tanks with agitators, to pressure neutralisation and in the end to pipe reactors in the granulator and/or the dryer. The last process is the most energy efficient and is state-of-the-art today: phosphoric acid and ammonia are used in a granulation unit with pipe reactor to produce the fertiliser diammonium phosphate. Transport of ammonia to the diammonium phosphate plant is included with the respective fuel demand and assumed by tanker and train.
Dolomite	• Dolomite, at plant	Technology for limestone mining, crushing, and milling assumed as a first approximation. An overall yield of 95% is assumed.
Nitric acid (98%)	• Nitric acid (98% HNO_3), at plant	Nitric acid is produced from the oxidation of ammonia with air following this process: $4\ NH_3 + 5\ O_2 \Rightarrow 4\ NO + 6\ H_2O$ Undesired reactions: $4\ NH_3 + 3\ O_2 \Rightarrow 2\ N_2 + 6\ H_2O$ $4\ NH_3 + 4\ O_2 \Rightarrow 2\ N_2O + 6\ H_2O$ The production of nitric acid bases on the following chemical operations: a) Oxidation of ammonia with air to give nitric oxide and b) Oxidation of the nitric oxide to nitrogen dioxide and absorption in water to give a solution of nitric acid. The nitric acid process involves the following main unit operations in their sequential order: air filtration, air compression, air/ammonia mixing, air/ammonia oxidation over catalytic gauzes, energy recovery by steam generation and/or gas re-heating, gas cooling, gas compression, energy recovery and cooling (dual pressure plants only), absorption, with the production of nitric acid, waste gas (tail gas) heating, energy recovery by expansion of the waste gas to atmosphere, in a gas turbine. The reaction from ammonia to nitric acid is exothermic. Therefore, steam is created in the process. Furthermore, nitrogen oxides to air and nitrous oxide to air are produced. In a few plants, N_2O emissions are abatted by catalytic decomposition, where N_2O is split into N_2 and O_2 by a catalyst.
NPK (15% N, 15% P_2O_5, 15% K_2O)	• NPK (15% N, 15% P_2O_5, 15% K_2O), at plant • NPK (15% N, 15% P_2O_5, 15% K_2O), as N, at plant • NPK (15% N, 15% P_2O_5, 15% K_2O), as P_2O_5, at plant • NPK (15% N, 15% P_2O_5, 15% K_2O), as K_2O, at plant	NPK is a multinutrient compound fertiliser with various N, P_2O5 and K_2O contents. In the modelled case, an N, P_2O_5 and K_2O content of 15 % each is assumed. The fertiliser production is modelled according to the nitrophosphate route. In the production process of NPK fertilisers via the nitrophosphate route, phosphorus is added as rock phosphate and the rock phosphate is digested with nitric acid. This route includes two steps. In the first step nitrophosphoric acid and calcium nitrate are produced by digesting rock phosphate with a large amount of nitric acid. To crystallise the calcium nitrate, the solution is cooled. Then the nitrophosphoric acid is neutralised with ammonia and in the last

Fertiliser	Datasets	Process description
		step a solid compound fertiliser is obtained by granulating or prilling.
Phosphate rock (32% P_2O_5)	• Phosphate rock (32% P_2O_5), at plant	Rock phosphate has a phosphorus content of 32 % P_2O_5 and is mainly used as a raw material for the production of P containing fertilisers. In this case the process is based on magmatic apatite phosphate ore (e.g. from Russia, as modelled in this process). To produce 1 tonne of commercial phosphate rock with a content of 32 % P_2O_5, 5 tonnes phosphate ore must be mined and beneficiated in open pit or underground mines. The rock phosphate processing is energy intensive due to the mining, crushing and grinding of the phosphate ore. The phosphated sludge is assumed to be deposited on a landfill site and treated as an inert substance.
Phosphoric acid (54% P_2O_5)	• Phosphoric acid (54% P_2O_5), at plant • Phosphoric acid, as P_2O_5, at plant	Phosphoric acid is an ancillary product, mainly used in the fertiliser manufacturing industry to produce P containing fertilisers. Phosphate rock and sulfuric acid are the raw materials to produce phosphoric acid. Phosphate minerals are digested with an acid. There are different methods to manufacture phosphoric acid. The main processes are the hemihydrate and the dihydrate process. The hemihydrate process is more energy efficient while the dihydrate process is simpler to operate. In the modelled process a combination of the dihydrate and the hemihydrate production process is assumed in the relation 80% to 20%. An average transport distance of the phosphate rock to the phosphoric acid plant is included with the respective fuel demand and assumed by tanker and train.
Potash salt	• Potash salt, 10% K_2O, at plant • Potash salt, as K_2O, at plant	Mining of potash salt.
Potassium chloride (60% K_2O)	• Potassium chloride (60% K_2O), at plant • Potassium chloride, as K_2O, at plant	Muriate of potash or potassium chloride is a fertiliser containing 60 % K_2O; the product can also be used as component in multi-nutrient fertilisers. Potassium chloride is produced by shaft mining and beneficiation. The modelled process includes the mining of potash salt. The incoming waste from the production is treated as inert material on a landfill site. Muriate of potash is produced in a wide variety of crystal sizes, according to the potash ore and process used. Different applications demand various particle-size distributions obtained by screening.
Sulfuric acid	• Sulfuric acid (100% H_2SO_4), at plant	Sulfuric acid is the most produced chemical in the world. Furthermore, it is an essential product to generate phosphoric acid and a key auxiliary chemical for the production of 80 % of the world's phosphate fertilisers. Therefore, the largest single sulfuric acid consumer is the fertiliser industry. There are several sources of sulfur in order to produce sulfuric acid: sulfur originating from crude oil or natural gas industry, sulfur originating from the metal industry and sulfur from pyrite mining. Besides, sulfuric acid can be produced by recycling, i.e. reusing, existing sulfuric acid. Sulfuric acid is produced from sulfur dioxide, its conversion into sulfur trioxide and flowingly, the adsorption of sulfur trioxide by water, resulting in sulfuric acid. Reactions are strongly exothermic, however depending on the production process of the sulfur dioxide: the production of sulfur dioxide from metal sulfate roasting and the regeneration of sulfuric acid are not exothermic. The production of sulfur dioxide is conducted on different ways, depending on the sulfuric acid production route: combustion of sulfur, combustion of sulfur containing gases, metal sulfide roasting, roasting of pyrite and sulfuric acid regeneration. For the use of sulfuric acid as an auxiliary product in the fertiliser production process it is assumed, that the sulfur enters the

Fertiliser	Datasets	Process description
Triple superphosphate (46% P_2O_5)	• Triple superphosphate (46% P_2O_5), at plant • Triple superphosphate, as P_2O_5, at plant	system free of burden. This assumption is confirmed by the oil and gas industry. The reason is explained below: most crude oil and gas deposits found around the globe contain a varying proportion of sulfureous compounds. At a refinery, the sulfur is stripped from the feedstock to ensure that the fuel products produced from the refining operations can meet government requirements for allowable sulfur content (typically <10 ppm for road transport fuels in many jurisdictions). Thus, it can be said that refineries would not produce elemental sulfur if they did not have to. The same amount of sulfur would be produced even if no application existed for it. All the refinery emissions and the cost of desulfurisation are currently allocated to the hydrocarbon products. Sulfur in crude gas streams is generally in the form of hydrogen sulfide and is removed at the wellhead before transport. Environmental regulations prevent its incineration and so it is extracted as elemental sulfur. Triple superphospate is a fertiliser containing 46 % P_2O_5. To produce triple superphosphate, rock phosphate is acidulated with phosphoric acid. Triple superphosphate production differentiates two methods: a) the two-step process and b) the slurry process. Today, more than 75 % of triple superphosphate is produced according to the first method. The two-step process runs as follows: in the first step a powder is made (where rock grinding consumes the most energy), in the second step this powder is granulated with steam. The basis for the slurry process is phosphoric acid with a concentration of 42% P_2O_5. Energy consumption in this process is 20% less than in the two-step process. However, this process is not always to prefer, because very soft rock is needed and problems with unreacted rock in the product occur.
Urea (46% N)	• Urea (46% N), at plant • Urea, as N, at plant	Urea is a nitrogen fertiliser containing 46 % N. It contributes to a large amount to the world's nitrogen fertiliser production. The combination of ammonia and carbon dioxide at high pressure is the basis of the commercial synthesis of urea. This way the ammonium carbamate is formed, which is then dehydrated by the application of heat to form urea and water ($2NH_3 + CO_2$ <-> NH_2COONH_4 <-> $CO(NH_2)_2) + H_2O$). In this process, the CO_2 comes directly from the ammonia synthesis. The amount of CO_2 used for the urea production is exactly the amount emitting from the ammonia process. Therefore, urea production is most often combined with an ammonia plant.
Urea ammonium nitrate (30% N)	• Urea ammonium nitrate (30% N), at plant • Urea ammonium nitrate, as N, at plant	Urea ammonium nitrate is a liquid fertiliser with 28 - 32 % N content. In the modelled case, an N content of 30 % is assumed. Urea ammonium nitrate solutions are produced through mixing and cooling of concentrated urea and ammonium nitrate solutions. Here both continuous and batch processes are available. In this process, the CO_2 for the liquid urea necessary for the manufacturing of urea ammonium nitrate comes directly from the ammonia process output: the amount of CO_2 used for the liquid urea production is exactly the amount emitting from the ammonia process. Therefore, urea production is most often combined with an ammonia plant.

1.2 Allocation

Ammonia, nitric acid and sulfuric acid production generate steam as a co-product. An economic allocation has been performed for ammonia, nitric acid and sulfuric acid based on market values (Tab. 2).

Tab. 3 shows the final allocation factors applied.

Tab. 2: Market values used for the allocation of fertiliser precursors

Product	Market value	Comment
Steam	15 EUR/t	Indicative value provided by Yara for high-pressure steam
Ammonia	333 EUR/t	Data from Fertilisers Europe
Nitric acid	127 EUR/t	Extrapolated from the ratio for production costs of nitric acid and ammonia is 0.381:1
Sulfuric acid	63 EUR/t	Data from Fertilisers Europe

Tab. 3: Allocation values for fertiliser precursors and co-products

Product	Allocation
Ammonia, from steam reforming process	97.6 %
Steam from ammonia production	2.4%
Nitric acid	93.0%
Steam from nitric acid production	7.0%
Sulfuric acid	78.4%
Steam from sulfuric acid production	21.6%

For multi-nutrient fertilisers, an allocation has been applied to distribute the impacts between their N, P_2O_5 and K_2O fractions, starting from production datasets per kg of product. The following multi-nutrient fertilisers are concerned: ammonium nitrate phosphate, diammonium phosphate, monoammonium phosphate, NPK 15-15-15, NPK 26-15-15 and potassium nitrate. Allocation has been applied for the following geographies: CN, RER, RNA et RoW.

Allocation factors for multi-nutrient fertilisers are calculated based on data retrieved from a carbon footprint calculation tool developed by Fertilisers Europe (2016). This tool computes the carbon footprint for compound NPK (15-15-15) fertilisers produced via the so-called mixed-acid and nitro-phosphate routes. The tool calculates the contribution of the various building blocks of the processes separately to CO_2-eq emissions. CO_2-eq emissions are aggregated per ton NH_4-N, NO_3-N, P2O5 and K2O and include emissions from the use of feedstock and fuel, steam, electricity as well as direct N_2O and CH_4 emissions for each building block (NH_4-N, NO_3-N, P_2O_5 and K_2O).

It is estimated that 25% of the NPK (15-15-15) production takes place through the nitro-phosphate route and 75% through the mixed-acid route (expert judgement). These calculations provide the following carbon footprints per kg N, P_2O_5 and K_2O to produce NPK (15-15-15):

- 3.22 kg CO_2 eq / kg N
- 0.37 kg CO_2 eq /kg P_2O_5
- 0.41 kg CO_2 eq /kg K_2O

We consider that these carbon footprint scores are representative of a physical allocation related to each building block of the manufacturing process. We thus use these carbon footprint values to develop allocation factors for all multi-nutrient fertilisers. Please contact Fertilisers Europe in case there are further questions on this tool.

Tab. 4 presents the final allocation values for all multi-nutrient fertilisers.

Tab. 4: Allocation factors for multi-nutrient fertilisers

Product		Allocation
Ammonium nitrate phosphate (ANP) (with 22%N, 22% P2O5)	as N	89.6%
	as P_2O_5	10.4%
Diammonium phosphate (with 18%N, 46% P2O5)	as N	77.1%
	as P_2O_5	22.9%
Monoammonium phosphate (MAP) (with 8.4%N, 52% P2O5)	as N	58.1%
	as P_2O_5	41.9%
NPK (15-15-15)	as N	80.3%
	as P_2O_5	9.4%
	as K_2O	10.3%
NPK (26-15-15)	as N	87.6%
	as P_2O_5	5.9%
	as K_2O	6.5%
Potassium nitrate (with 14%N, 44% K2O)	as N	71.2%
	as K_2O	28.8%

1.3 Regionalization

The ammonia and nitric acid datasets have been regionalized for 10 continental zones, with a differentiation in feedstock and fuel, steam and electricity for ammonia and N_2O direct emissions for nitric acid. Tab. 5 and Tab. 6 show respectively the regional parameters for ammonia and nitric acid production for 10 continental zones. For ammonia production in China, two technologies are differentiated: the steam reforming process and the partial oxidation process. The partial oxidation process is used for the gasification of heavy feedstocks such as residual oils and coal (in this case, coal is used as fuel and feedstock). It is a non-catalytic process taking place at high pressure (> 50 bar) and temperatures around 1,400°C.

Tab. 5: Regional parameters for ammonia production for 10 continental zones

Ammonia	Ecoinvent geographical code	Feedstock and fuel (GJ/t ammonia)	Steam (GJ/t ammonia)	Electricity (GJ/t ammonia)
EU average 2013/14	RER	34.03	-1.49	0.84
North America	RNA	34.89	0	0
Latin America	RLA	41.38	0	0
Africa	RAF	36.71	0	0
Middle East	RME	35.75	0	0
CIS (Russia Commonwealth)	FSU	39.49	0	0
South East Asia	UN-SEASIA	37.45	0	0
South Asia	SAS	42.81	0	0
Oceania	UN-OCEANIA	32.11	0	0
China, gas based (steam reforming process)	CN	39.49	0	0
China, coal based (partial oxidation process)	CN	44.26	0	0

Tab. 6: Regional parameters for nitric acid production for 10 continental zones

Nitric acid	Ecoinvent geographical code	N_2O emissions (kg/t nitric acid)
EU average 2014	RER	0.7
North America	RNA	5.4
Latin America	RLA	4.7
Africa	RAF	4.7
Middle East	RME	6.5
CIS (Russia Commonwealth)	FSU	5.6
South East Asia	UN-SEASIA	5.9
South Asia	SAS	4.5
Oceania	UN-OCEANIA	5.2
China	CN	7.4

For products that use ammonia and nitric acid (such as ammonium nitrate, urea, etc.), the datasets have been duplicated for 3 zones: North America, China, RoW. The RoW processes use the ammonia and nitric acid production weighted average of the other 7 continental zones. Other flows (electricity, water, other inputs, etc.) in these datasets have also been regionalized.

Tab. 7 shows the production weighted average ponderation for the ammonia and nitric acid RoW processes. Shares of ammonium nitrate and calcium ammonium nitrate production are taken as a proxy for nitric acid production given that they are the main products using nitric acid. The ammonia, ammonium nitrate and calcium ammonium nitrate production data are based on 2015 production data from the International Fertilisers Association.

Tab. 7: Production weighted average ponderation for the ammonia and nitric acid RoW processes

Production weighted average for RoW processes	Ammonia	Ammonium nitrate (AN) and Calcium ammonium nitrate (CAN)
Latin America	5.57%	2.88%
Africa	7.00%	9.61%
Middle East	21.38%	7.16%
CIS (Russia Commonwealth)	22.39%	76.92%
South East Asia	10.30%	0.00%
South Asia	32.34%	3.43%
Oceania	1.02%	0.00%

2 Plant production

2.1 Principles for data collection

Inventory data is collected for the main exporting countries of every crop included in the World Food LCA Database (WFLDB). The objective is to cover at least 50% of the global export. In some cases (e.g. carrots, orange, pear or tomato) the combined export share of all countries included in WFLDB is lower than 50%. When export data are not available for crops, countries which together account for at least 50% of the global production are included.

In addition to country-specific datasets, a global average (GLO) is modelled for all crops, calculated based on the export or production shares of the selected countries. Export and production shares used in the WFLDB are obtained from FAOSTAT. The are some exceptions to this approach for which the datasets were developed for specific countries only (e.g., mint or vanilla).

2.2 Yield and allocation

Harvest of straw as a co-product is considered for crops as oat, rice, barley and wheat. For oat, the yield for straw is calculated using the straw to grain-ratio (Flisch et al. 2009) and the assumption that only half of the straw is removed from the field. Economic allocation is applied, assuming a price ratio of grain to straw of 92% to 8%. For barley and wheat, yields and economic allocation factors are derived from FEFAC (2015), considering a wheat grain to wheat straw mass ration of 1.79, and 79% allocation to wheat grain vs. 21% to wheat straw; considering a barley grain to barley straw mass ration of 1.45, and 76% allocation to barley grain vs. 24% to barely straw. For rice, a grain to straw ratio of 1.38 is considered, based on IPCC 201 (Vol 4, Ch 11, Table 11.1A and Feedipedia).

Harvest of maize stover is considered, with yields derived from FEFAC (2015), and economic allocation factors of 95% to maize grain and 5% to maize stover, assuming 15% stover removed from the field and 65 $/t stover (Whitman et al. 2011).

Harvest of husk as a co-product is considered for coconut and shea. For coconut, the yield is based on company data in the Philippines. Economic allocation is applied with 93% allocated to the dehusked coconut and 7% to the husk. For shea, the yield and allocation are based on a reference for processing in Burkina Faso (see section 5.25.4).

2.3 Fertiliser application

Data about mineral fertiliser use consist of the total amount of nutrients applied as well as the share of fertiliser types in percentages. The following decision tree was applied to determine the overall data level (in green on Figure 1) for mineral fertilisers.

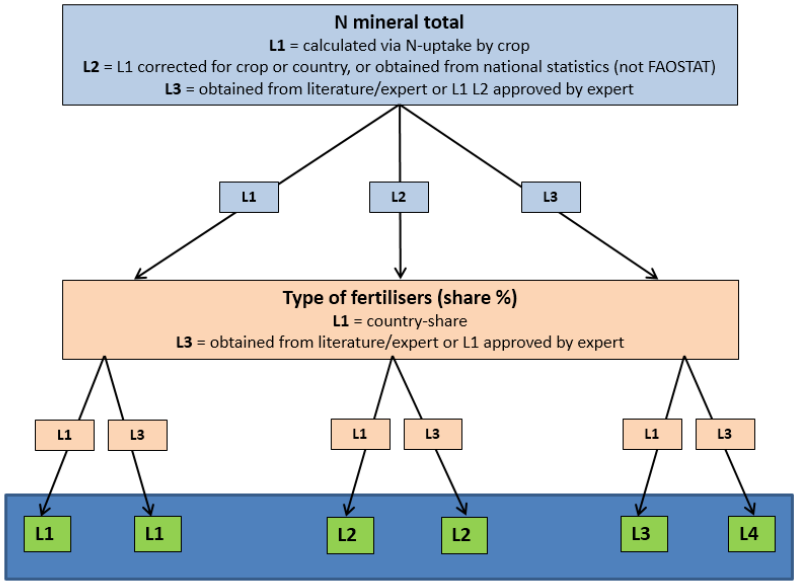

Figure 1: Decision tree for defining data levels for mineral fertilisers

2.3.1 Mineral and organic fertilisers, L3 and L4 data

Literature or expert data is available for total manure application (liquid and solid), the total amount of N, P_2O_5 and K_2O applied by mineral fertilisers as well as the type and amount (%) of mineral fertiliser used. If the amount of mineral fertilisers applied is at L3 but the type of fertiliser at L1, the overall data level is L3. If both the total amount of mineral fertilisers applied as well as the fertiliser type are at L3, the overall data level is L4 (see figure above).

2.3.2 Total N, P and K fertilisers, L1 data

If no L3 or L4 data is available, the following approach is used to calculate L1 data. The total amount of N (kg N), P (kg P_2O_5) and K (kg K_2O) fertilisers applied per hectare and year are calculated according to the WFLDB Methodological Guidelines 3.9 (Nemecek et al. 2023), i.e. by multiplying the nutrient content of a crop by its yield in a given country. Information on nutrient contents of main products and crop residues are available from the Swiss Federal Food Safety and Veterinary Office (2014), Flisch et al. (2009), Souci et al. (2000) and INRA et al. (2015). For total P and K fertilisers only the nutrient content of the main product is considered. For total N applied, the harvested products as well as crop residues such as straw and haulms are taken into account. For cereals, the yield of crop residues is obtained via a harvest-ratio, which expresses the proportion of harvested straw and haulms to harvested grains as documented in Flisch et al. (2009).

2.3.3 Mineral and organic fertilisers, L1 data

A ratio of N applied as mineral fertilisers to N total (organic and mineral fertilisers) of 0.8 (expert judgement) is assumed for all crops and countries (L0). Based on this ratio and the total N applied as fertilisers, the amount of N applied as mineral fertilisers is calculated (crop and country-specific data).

FAOSTAT (2012) provides the manure N content (kg N in manure) per animal category on a country level (average from 2009-2012 was used). Based on these data, the share of liquid and solid manure per animal category and country is calculated, assuming 50% liquid and 50% solid manure for cattle, pigs and laying hens, and 100% solid manure for all other animal categories. In addition, the ratio of N in liquid to N in solid manure per country is calculated from these data.

Nutrient contents of manure (kg N_{av}/ kg P_2O_5/ kg K_2O per m^3 liquid and tonnes solid manure) are provided in Flisch et al. (2009). These contents and the share of liquid and solid manure per animal category are used to calculate the average N, P and K content in liquid and solid manure for a specific country, assuming a dilution level of 50% for liquid manure.

These data allowed calculating all other fertiliser inputs (crop- and country specific). Solid and liquid manure applied per crop and country is calculated from the total amount of N applied as organic fertilisers, the ratio of N in liquid to N in solid manure per country and the average N content in liquid and solid manure. Based on the average P and K content in liquid and solid manure, P and K applied as organic fertilisers are calculated. Total P and K applied as mineral fertilisers re obtained by taking the difference of total P and K fertilisers calculated via the nutrient content (see above) and P and K from organic fertilisers. Negative values were set to zero, i.e. no mineral fertilisers are applied.

The share of mineral fertiliser types per country are based on statistics provided by IFA (International Fertiliser Association; www.fertiliser.org) for a time period of four years (average of 2009-2012), as described in the WFLDB Methodological Guidelines 3.9 For Ghana and Vietnam, no country-specific data are available; therefore, the world share (L0) is used.

2.4 Machinery processes

For machinery and work processes, literature or expert data is available for the total diesel combusted in agricultural machinery (L3) or for individual work processes (L4, see below).

If no literature or expert data is available, the modified MEXALCA approach is applied to estimate specific field operations (L1) using the following formula:

$$M_t^c = \sqrt{\frac{mach_t}{mach_0}}$$

M_t^c: Variable machinery use in the target country compared to the variable machinery us in the original country (-)
$mach_t$: Agricultural index for machinery use intensity in the target country (-)
$mach_0$: Agricultural index for machinery use intensity in the original country (-)

For soil tillage, the following formula with tillage indices (*till*) is used:

$$M_t^c = \frac{till_t}{till_0}$$

In general, work processes obtained by the MEXALCA approach have to follow the other inputs (i.e. when pesticides are applied for a specific dataset, the machinery process sprayer has to be > 0). In cases where work processes obtained by the MEXALCA approach contradicted these other inputs, the work process is adapted on L2. This included the following cases:

Fertilising with broadcaster (number of passes) is adapted according the number of N applications.

Planting trees is adapted according to the number of planted trees used in the dataset.

In addition, agronomic corrections are applied on L2 as indicated in Tab. 8. The machinery input is modelled as work processes including the machinery and energy carriers for working 1 ha (Tab. 9).

Tab. 8: Agronomic corrections applied to machinery processes

All crops
Fertilising, with broadcaster has to be > 0 if mineral fertilisers are applied.
Transport, tractor and trailer has to be > 0 for all crops. If no MEXALCA data are available, the distance from the field to the farm is assumed to be 2 km as a proxy (L0), which is multiplied by the yield.
Arable crops
Soil cultivation processes have to be applied for the cultivation of arable crops. Soil preparation (plough and chisel together) is done once per year (values between 0.7- 1.5). Higher values are adapted accordingly. Sowing and harvesting generally occurs once per year. Therefore, these processes are set to 1 in L2.
Perennial crops
Soil cultivation processes are not considered (i.e. are set to zero on L2), because only the productive phase is regarded.
Mowing (motor or rotary mower) or mulching is considered to occur once by default.

Tab. 9: List of machinery work processes per ha

Plant protection
Sprayer (total number of passes)
Broadcaster (for the application of solid pesticides, e.g. granulate; number of passes)
Flaming (number of passes)
Soil cultivation
Tillage method C2 (0=Unknown, 1=Fall plow, 2=Spring plow, 3=Mulch tillage, 4=Ridge tillage, 5=Zone tillage, 6=No tillage)
Anti-erosion practice P (0=Unknown, 1=Up & down slope (no practice), 2=Cross slope, 3=Contour farming, 4=Strip cropping, cross slope, 5=Strip cropping, contour)
Work processes
Soil separation (number of passes)
Soil tillage, chisel (number of passes)
Soil tillage, spring-tine weeder (number of passes)
Soil tillage, rotary harrow (number of passes)
Soil tillage, spring-tine harrow (number of passes)
Soil tillage, hoeing and earthing up, potatoes (number of passes)
Soil tillage, plough (number of passes)
Soil tillage, roll (number of passes)
Soil tillage, rotary cultivator (number of passes)
Soil tillage, generic (number of passes)
Sowing, planting
Sowing (number of passes) – for arable crops and horticulture
Planting seedlings (number of passes)– for arable crops and horticulture
Planting and establishing of orchard (number of trees divided by the lifetime of the orchard) – for trees
Planting potatoes (number of passes)
Fertilisation
Mineral fertilisers
Fertilizing, with broadcaster (number of passes)
Fertilizing, liquid application (number of passes)
Organic fertilisers
Liquid manure application with vacuum tanker (m^3)
Solid manure application (t)
Harvesting
Chopping maize (number of passes)
Threshing with combine harvester (number of passes)
Harvesting beets with complete harvester (number of passes)
Harvesting potatoes with complete harvester (number of passes)

Harvesting, with complete harvester (number of passes)
Sorting potatoes
Removing potato haulms (number of passes)
Windrowing with rotary swather (number of passes)
Loading bales (no. of bales)
Rooting up trees (i.e. the disposal of wood from trees to incineration; per ha and divided by the lifetime of an orchard)
Other work processes
Mulching (number of passes)
Chopping (number of passes)
Mowing with motor mower (number of passes)
Mowing with rotary mower (number of passes)
Transport, tractor and trailer (tonnes * km)

2.5 Other inputs

2.5.1 Materials and installations

The following materials and installations are considered when specific information existed (L3 data):

- Covering sheets (foil used for asparagus cultivation)
- Plastic tunnel (used for open-field cultivation of strawberries)
- Greenhouse (for tomato and strawberries cultivated in the greenhouse)
- Trellis system (i.e. wooden poles and wires used as mechanical support to grow trees), unless otherwise specified

2.6 Direct emissions from crop production

2.6.1 Methane emissions in rice cultivation

The specific assumptions regarding the emission factors for the two producing countries modelled with the legacy crop modelling method are presented in Tab. 10.

Tab. 10:Assumptions for methane related parameters for rice production in China and India

	China	India
Scaling factor to account for the water regime during the cultivation period ($SF_{w)}$	0.6 (single aeration)	0.78 (unknown)
Scaling factor to account for the water regime before the cultivation period ($SF_{p)}$	1 (non-flooded pre-season < 180 days)	1.22 (unknown)
Scaling factor to account for the type and amount of organic amendment applied (SF_O)	1 (no organic amendments)	1.16 (2 t ha^{-1} manure (L3 data))
Duration of cultivation period	91 days (2 crop cycles per year)	153 days (1 crop cycle per year)

Information regarding specific soil types is not available. Based on these scaling factors and the baseline emission factor, adjusted daily emission factors are calculated using equation 5.2 (IPCC 2006). These adjusted daily emission factors and the cultivation period are used in equation 5.1 (IPCC 2006) to calculate the methane emissions per crop cycle, which are 71 kg and 219 kg in China and India, respectively. The lower amount of methane emitted from rice grown in China results from more specific data for this country as well as the fact that only one crop cycle is considered instead of one year. Rice in China is produced twice a year, whereas in India there is only one crop cycle per year.

2.6.2 Emissions from tropical crop residues

For cocoa, coffee and cashew nuts, a large part of the fruit production represents residues: pod husk for cocoa, cherries pulp and mucilage for coffee and cashew apple for cashew nuts. These residues are often improperly managed and required specific end-of-life modelling.

Approximatively 75% of the fresh cocoa pod is made of husk and pulp (70% husk, estimated 5% pulp, based on Yapo et al. 2013), while 25% is made of the wet beans. Considering that the wet beans lose 60% of their weight when dried (based on information from WFLDB partners), **there are 7.5 kg fresh husk and pulp for 1 kg dry beans**. Husk and pulp contain 85% moisture. The pulp drains away as a liquid (sweating) in the fermentation and is not considered in the calculation of the husk waste management impact. Therefore, we consider 1.05 kg husk dry matter per kg dried beans. According to a WFLDB partner, 55% of the husks can be considered dumped as non-aerated heap.

Coffee cherries pulp contain 77% water (Braham et al 1979). The amount of fresh pulp per coffee beans (3.35 kg/kg) was determined with the WFLDB partners.

The ratio of cashew apple to cashew nut is considered to be 8 kg/kg (average ratio given in literature as for example a ratio around 9.7 kg/kg in Murugan (2015), a ratio of around 6.7 mentioned in Costa (2017) and a ratio of 8 kg/kg in Oliveira (2008)). Cashew apples may be consumed raw, processed into juice or other edible products such as chutneys. However, according to Costa (2017), 95% of cashew apples are not actually used after harvesting in India and West Africa, therefore it is considered as a post-harvest waste.

In absence of better information at country level, 50% of the biowaste is considered dumped as non-aerated heap. The other 50% is considered spread on field shortly after production.

The following datasets have been created, based on the internal Quantis tool "Advanced composting tool, version 2022" for biowaste with high moisture content and in wet tropical conditions, in line with IPCC 2019 guidelines for waste disposal:

- Biowaste treatment by non-aerated heap, husks, wet tropical conditions, per kg DM

Typically applies to biowaste with high moisture content (85%) and large fibrous proportion, such as cocoa pod husks.

Model adapted for non-aerobic conditions and without infrastructure or mechanised work. This results in high level of methane emissions (fraction of 20% of the degraded C, that is MCF of 0.4 (IPCC 2019, vol 5, Table 5.1, MCF for unmanaged shallow (<5 m waste)) and F of 0.5 (IPCC 2019, vol 5, p.10). The rest is emitted as CO_2 (68%) or VOC (4%) or is transformed into humic substances (8%). The total degraded fraction is considered to be 73% before it is spread on the soil. The rest is mainly leached into surface water or into soil (estimated 20%) or remains on soil for an undetermined period of time as degraded waste (estimated 10%). These estimates are not critical as long as biogenic CO_2 is not characterised, in general, as climate change indicator in LCIA methods.

- Biowaste treatment by non-aerated heap, pulp, wet tropical conditions, per kg DM

Typically applies to biowaste with high moisture content (76.7%) such as coffee cherries pulp.

Model adapted for non-aerobic conditions and without infrastructure or mechanised work. This results in high level of methane emissions (fraction of 20% of the degraded C, that is MCF of 0.4 and F of 0.5 based on IPCC 2019 for SWDS). The rest is emitted as CO_2 (71%) or VOC (2%) or is transformed into humic substances (6%). The total degraded fraction is considered to be quite high: 86% before it is spread on the soil. The rest is mainly leached into surface water or into soil (estimated 7%) or remains on soil for an undetermined period of time as degraded waste (estimated 7%). These estimates are not critical as long as biogenic CO_2 is not characterised as GHG emission.

- Biowaste treatment by spreading on field, wet tropical conditions, per kg DM

Applies to any biowaste.

Model adapted for semi-aerobic conditions and without infrastructure or mechanised work. This results in moderate level of methane emissions (fraction of 5% of the degraded C, that is MCF of 0.1 and F of 0.5 based on IPCC 2019 for SWDS). The rest is emitted as CO_2 (86%) or VOC (3%) or is transformed into humic substances (5%). The total degraded fraction is considered to be quite low: 20% before it is spread on the soil. The rest is mainly leached into surface water or into soil (estimated 40%) or remains on soil for an undetermined period of time as

degraded waste (estimated 40%). These estimates are not critical as long as biogenic CO_2 is not characterised as GHG emission.

Data sources:

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Murugan S, Kumar S, Rajan J K, Varshney L, Kumar V, 2015. Cashew apple (Anacardium occidentale): evaluation of physical and chemical composition. Indian Journal of Natural Sciences, vol 5 (29). Downloaded on https://www.researchgate.net/profile/Senthil_Murugan13/publication/307508432_Cashew_Apple_Anacardium_occidentale_Evaluation_of_Physical_and_Chemical_Composition/links/5d1cbbab92851cf44060e2fd/Cashew-Apple-Anacardium-occidentale-Evaluation-of-Physical-and-Chemical-Composition.pdf, August 2019.

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2.6.3 Grass and grass-based products

2.6.3.1 Overarching approach

Grass is a generic term for a variety of plant species that can be consumed by grazing animals, under climatic conditions covering practically all land masses of the planet. Grass is produced in grasslands under a broad diversity of human practices, from no intervention to fully controlled, fertilised and irrigated fields. Therefore, a certain level of simplification has been required to address this diversity.

Grass production is used as an input for three grass products (used as ingredients and mixtures in the feed approach): grazed grass, hay and grass silage. These products are described at the end of this section.

Tab. 11 displays the 5 productivity levels and the 3 intensity levels that have been retained for modelling grassland. This results into 15 archetypes that are used to model country or regional mixes for all grass products. For the yield, ray grass (*Lolium perenne*) has been used as a reference grass for all archetypes, except tropical ones, for which elephant grass (*Pennisetum purpureum*) is the reference.

Tab. 11: Grassland yield (t dry matter grass per ha.year) according to the soil / climatic productivity of the area and to the intensity of the agricultural practices

Grassland productivity levels	Minimal intensity	Low-medium intensity	High intensity
Low productivity, cool and dry (North, mountain)	0.8	1.4	2
Medium productivity (cool wet to warm dry)	2	3.5	5
High productivity (temperate to warm and wet)	3.2	5.6	8
Very high productivity (warm temperate and wet or irrigated)	5	8.75	12.5
Extremely high tropical productivity (non-seasonal conditions)	7	12.25	17.5

The 5 productivity levels, based on Huyghe et al. (2014), are described as follows:

Low productivity, cool and dry: refers to regions where vegetation is limited mostly by low temperature, short summers and small precipitations. Mostly northern regions, tundra or alpine tundra.

Medium productivity (cool wet to warm dry): refers to regions where vegetation is limited by low temperature but not limited by precipitations, or conversely by short precipitation season but not by temperature. Can be wet northern regions or savanna.

High productivity (temperate to warm and wet): refers to regions where vegetation is mostly limited by seasonality, typically in temperate regions with a productive summer and a cold winter.

Very high productivity (warm temperate and wet or irrigated): refers to regions where vegetation can grow all-year round with appropriate temperatures and moisture levels. Can be sub-tropical well rain-fed regions, or temperate regions such as Ireland, UK Midlands, Normandy or Belgium. Also refers to lower productivity regions that are naturally limited by water input but are irrigated.

Extremely high tropical productivity (non-seasonal conditions): refers to regions where vegetation experiences optimal conditions all year round, only limited by its own biology.

The 3 intensity levels are described as follows, and more specifically in Tab. 12:

- Minimal intensity: no intervention on grass growth.
- Low-medium intensity: extensive practices, limited input of fertilisers, no frequent re-seeding.
- High intensity: intensive practices, high inputs of fertilisers and frequent re-seeding. Irrigated in some cases (see below).

Tab. 12: Key parameters describing the intensity levels of grass production agricultural practices. These values are the results of a literature review and internal expert knowledge.

Productivity levels	Mineral fertilisers input (kg ha^{-1} a^{-1})			Tillage and re-seeding	Irrigation
	N	P	K		
Minimal intensity	0	0	0	None	None
Low-medium intensity	30	12.5	25	Every 5 to 10 years (10-20% each year, hence 15% in average)	None
High intensity	100	27.5	55	Every 2 to 5 years (20-50% each year, hence 35% in average)	10% if very high productivity

Main reference used : Huyghe et al 2014.

Other references: Agreste Basse-Normandie 2008, Cerri et al 2016, Drewry et al 2008, , Orr et al 2016, Pérez-Prieto and Delagarde 2013, Qi et al 2017, Rotz et al 2019, Ruviaro et al 2015, Saouter et al 2016, Suttie et al 2005.

When low productivity conditions are enhanced by irrigation, the area becomes of very high productivity (assuming this is not done in cold conditions, but in warm dry conditions). For this reason, instead of creating 3

additional archetypes, the very high productivity regions under high intensity agricultural practices also contain the irrigated cases. By default, it is considered that 10% of the very high productivity regions under high intensity agricultural practices are actually lower productivity areas that are improved by irrigation. This might depend on country, but the model does not reach this level of refinement.

For every country or region, the proportions of grass production archetypes are defined for region productivity and agricultural intensity. An example for Europe of such proportions is given in Tab. 13. These mixes are based on estimates and simplified (typically contributions below 5% are grouped with similar categories) and are used to calculate average yield.

Tab. 13: Grass production archetypes mix for Europe (percentage of the grassland area)

Estimated region mix, RER	Minimal intensity	Low-medium intensity	High intensity	Total by productivity
Low productivity, cool and dry (N, mountain)		10.0%		10%
Medium productivity (cool wet to warm dry)		16.0%	24.0%	40%
High productivity (temperate to warm and wet)		12.0%	18.0%	30%
Very high productivity (warm temperate and wet or irrigated)		8.0%	12.0%	20%
Extremely high tropical productivity (non-seasonal conditions)				0%
Total by intensity	0%	46%	54%	100%

With the example above, the average yield is 6.2 t DM/ha.a. Moreover, the low-medium intensity farms produce 33.4% of the grass with an average yield of 4.5 t DM/ha.a, while the high intensity farms produce 66.6% of the grass with an average yield of 7.7 t DM/ha.a.

2.6.3.2 Peat degradation and land use change

The GHG emissions related to peat degradation are added to the datasets based on national statistical data from Joosten (2010). It means they cannot be added at the archetype level, hence they are added when the dataset is regionalised.

Land use change (LUC) is not taken into account for grass production. The approach has been adopted with the intention of including LUC for grass as for any other crop. However, the WFLDB is bound with a LUC assessment tool that does not handle grass as a crop. The error induced by this restriction has been estimated using another LUC assessment tool and it appears the mismatch is not significant for the countries or regions assessed.

2.6.3.3 Grazed grass

In a first step, the grazed grass datasets are regionalised for each agricultural intensity levels. Therefore, they build on the archetypes of all productivity levels, but only of 1 intensity level (example for Europe given in Tab. 14). It is assumed the stocking rate does not exceed the livestock capacity, so the animals do not graze all the grass produced. Therefore, 0.9 kg is grazed only for each kg grown. Based on this, there is no erosion and no soil organic carbon loss due to bad practices.

Tab. 14: Grazed grass first step regionalisation, per agricultural intensity level (low-medium intensity example for Europe) (shares represent the grass production)

Grass datasets input for Grazed grass, low-medium intensity agricultural activities	Quantity per 0.9 kg grazed grass
Grass production archetype, **low productivity** conditions, low-medium intensity, per kg DM (WFLDB)/GLO U	0.068 kg
Grass production archetype, **medium productivity** conditions, low-medium intensity, per kg DM (WFLDB)/GLO U	0.270 kg
Grass production archetype, **high productivity** conditions, low-medium intensity, per kg DM (WFLDB)/GLO U	0.324 kg
Grass production archetype, **very high productivity** conditions, low-medium intensity, per kg DM (WFLDB)/GLO U	0.338 kg
Grass production archetype, **extremely high productivity** conditions, low-medium intensity, per kg DM (WFLDB)/GLO U	0 kg

In this step, the emissions associated to manure excreted on pasture are added in accordance with the average climate of the country or region. In addition, the peat degradation emissions are also added (section 2.6.3.2) (Joosten 2010).

In a second step, the final country or regional mix is built by assembling the datasets modelled in the 1st step. The resulting dataset is an ingredient that can be used directly in a feed basket.

2.6.3.4 Hay

The exact same approach is applied for hay as for grazed grass. However, it is considered that 100% of the grass yield is harvested (by definition of the yield measured). Instead of considering emissions from manure excreted on pasture, impacts related to harvesting, drying and storing are modelled. These activities are realised with different techniques that are correlated to the agricultural activities level of the grass production, as summarised in Tab. 15.

Tab. 15: Key parameters description of hay production archetypes

Productivity levels	Mechanised mowing	Haystacks	Drying on field	Drying in storage	Mechanised transportation
Minimal intensity	Yes	Not rolled	100%	0%	0.75 km
Low-medium intensity	Yes	Rolled in plastic net	25%	75%	1.5 km
High intensity	Yes	Rolled in plastic net	10%	90%	5 km

In this step, emissions from peat degradation are added.

In a second step, the final country or regional mix is built by assembling the datasets modelled in the 1st step. The resulting dataset is an ingredient that can be used directly in a feed basket.

2.6.3.5 Grass silage

The exact same approach is applied for grass silage as for hay. Impacts from harvesting, ensiling and storing are modelled. These activities are realised with different techniques that are correlated to the agricultural activities level of the grass production, as summarised in Tab. 16.

Tab. 16: Key parameters description of grass silage production archetypes

Productivity levels	Mechanised mowing	Ensiling	Mechanised transportation
Minimal intensity	Yes	Under plastic sheets at farm	0.75 km
Low-medium intensity	Yes	Baled in PE wrapper	1.5 km
High intensity	Yes	Baled in PE wrapper	5 km

In this step, emissions from peat degradation are added.

In a second step, the final country or regional mix is built by assembling the datasets modelled in the 1st step. The resulting dataset is an ingredient that can be used directly in a feed basket or can be used in a mixture, as an intermediate modelling step.

2.6.4 Concentrate mixtures and compounding

This category of feed includes products which contain a high percentage of protein (dry basis), such as oilseeds meal. The Tab. 17 lists the mixtures that are used in the WFLDB animal systems. Compounded mixes are typically transformed into pellets, while others are considered to be fed as they were produced.

Tab. 17: Concentrate mixtures used for animal feed

Dataset	Comment	Source
Concentrate feed, cereal based, for dairy cows, at farm	Compounded mix, GLO	Alig 2009
Concentrate feed, protein concentrate, for dairy cows, at farm	Compounded mix; regionalised mixes with different sourcing. Details are provided in section 4.3.2.	Alig 2009, FEFAC / Rabobank 2017[1]
Fishmeal, as feed, for monogastric animals	No additional process, GLO	Ecoinvent 3.5
Molasses, as feed (liquid)	No additional process, GLO	WFLDB
Oilseed meal mix, as feed	Compounded mix, regionalised mixes with different sourcing	WFLDB and FAOSTAT 2017
Palm kernel cake, as feed	Compounded mix, GLO	WFLDB
Protein mix compound feed, 100% soy, for monogastric animals	Compounded mix, GLO based on European soy mix	WFLDB, ecoinvent 3.5, FEFAC / Rabobank 2017 and GLEAM v2
Protein mix compound feed, 53% soy, for monogastric animals	Compounded mix, GLO based on European soy mix	
Protein mix compound feed, 84% soy, for monogastric animals	Compounded mix, GLO based on European soy mix	
Protein mix compound feed, 93% soy, for monogastric animals	Compounded mix, GLO based on European soy mix	
Wet distillers grains and solubles, as feed	No additional process, GLO	Ecoinvent 3.5

2.6.5 Cereal mixtures

This category groups cereals mixtures, a category particularly rich in energy. Tab. 18 lists the mixtures that are used in the WFLDB animal systems. The grains mixes are typically stored, sorted and dosed in mixes, processes that are grouped under a dataset called grain feed handling.

[1] https://research.rabobank.com/far/en/sectors/grains-oilseeds/the_european_feed_mix.html, accessed Fall 2019.

Tab. 18: Cereal mixtures used for animal feed

Dataset	Comment	Source
Grains mix, as feed, for broiler, industrial poultry system	Regionalised mixes with different sourcing	WFLDB and GLEAM v2
Grains mix, as feed, for layer hen, industrial poultry system	Regionalised mixes with different sourcing	WFLDB and GLEAM v2
Grains mix, as feed, for swine, backyard system	Regionalised mixes with different sourcing	WFLDB and GLEAM v2
Grains mix, as feed, for swine, industrial system	Regionalised mixes with different sourcing	WFLDB and GLEAM v2
Grains mix, as feed, for swine, intermediate system	Regionalised mixes with different sourcing	WFLDB and GLEAM v2
Grains mix, as feed, for ruminants	Regionalised mixes with different sourcing	WFLDB and GLEAM v2
Lupin seeds, as feed	Regionalised mixes with different sourcing	ecoinvent 3.5 and GLEAM v2

The grains mixes contain barley, oats, maize and wheat that are modelled using data from the Livestock Environmental Assessment and Performance (LEAP) database for 2017 (FAO 2017). The datasets are generated based on the differentiation of irrigated and non-irrigated production systems in the LEAP database. Specific input data include:

- Crop yield
- Total N, P and K fertilisers
- Pesticides
- Seeds
- Frequency of field work processes

The datasets describe the production of cereal grain, as main product, and straw/stover as co-products, with allocation based on their market share, as presented in Tab. 19:

Tab. 19: Allocation factors for main and co-products for barley, maize and wheat production datasets

Process	Co-products	Allocation factor	Data source
Barley grain, at farm	Barley grain	75.6%	FEFAC (2015)
	Barley straw	24.4%	
Oats, at farm	Oats (oat grain)	94.8%	FEFAC (2015)
	Oat straw	5.2%	
Maize grain, at farm	Maize grain	95%	Whitman et al. (2011)
	Maize stover	5%	
Wheat grain, at farm	Wheat grain	78.8%	FEFAC (2015)
	Wheat straw	21.2%	

2.6.6 Roughage mixtures

This category groups roughage mixtures, a feed category with high fibre content. It also includes bran, for practical reasons. The Tab. 20 lists the mixtures that are used in the WFLDB animal systems.

Tab. 20: Roughage mixtures used for animal feed

Dataset	Comment	Source
Bran mix, as feed	No additional process, GLO	WFLDB and GLEAM v2
Crop residues, as feed	Empty shell (no allocated impacts) and transportation, GLO	--
Fodder beet, as feed	No additional process, regionalised	WFLDB
Leaves, as feed	Empty shell (no allocated impacts) and transportation, GLO	--
Legumes and silage, as feed	No additional process, regionalised mix of different ingredients	WFLDB, ecoinvent 3.5 and GLEAM v2
Pulses straw, as feed	Empty shell (no allocated impacts) and transportation, GLO	--
Sugar beet pulp, as feed	No additional process, regionalised	ecoinvent 3.5
Sugarcane tops, as feed	Empty shell (no allocated impacts) and transportation, GLO	--
Swill, as feed, for monogastric animals	Empty shell (no allocated impacts) and transportation, GLO	--

2.7 Cocoa cultivation archetypes

Several archetypes have been defined for cocoa beans cultivation. Data have been collected or estimated by Barry Callebaut and Mars experts.

For West Africa (Côte d'Ivoire, Ghana, Cameroon), the following cocoa farming archetypes are considered:

- Low input
- Agroforestry
- Improved

For Brazil, Ecuador, and Indonesia, the following cocoa farming archetypes are considered:

- Medium input, intercropping
- Agroforestry
- Extreme high input

These archetypes are defined as follows:

- **Agroforestry** is also defined in a rather broad sense, where a (yet undefined) proportion of the shade trees are original/native forest trees and other shade trees were planted, e.g. Gliricidia. In the "agroforestry" cocoa farming archetype defined here, most trees don't have an economic value; they rather provide different ecosystem services.
- The **low input** archetype represents farms with no to medium shade, which are not very organised. Many farmers use no or only little fertilisers and pesticides (here an average situation is modelled).
- On "**improved**" farms, fertiliser and pesticide volumes applied are following official recommendations, which increases the cocoa yield by approx. 150 kg/ha.
- The "**medium input, intercropping**" archetype describes typical cocoa farms in South America and Indonesia, which use higher fertiliser amounts compares to West Africa, but also grow more fruit / coconut / rubber or other trees in between cocoa (light to medium shade), with an economic value for the in-kind use by the farmer, and/or for sale.
- The "**extreme high input farms**" are often bigger cocoa farms, which are irrigated, use improved planting material and 1 tonne or more of fertiliser per ha, apply mechanical pruning, and produce 2 tonnes or more cocoa beans per hectare. It is assumed that 10 – 15 % of the production in South America is delivered by extreme high input farms. For Indonesia, only a smaller share (5 % of total production) is assumed.

For all these farming systems and countries, data for yield, fertilisers and pesticides input and irrigation have been provided by Barry Callebaut and Mars experts. The emissions from husks residues are also modelled based

on WFLDB partners data and the IPCC framework (see section 2.6.2). In all these systems, other crops are cultivated on the same area as cocoa, a part before the cocoa trees become productive (up to 5th year) and a part as intercropping. These other crops can be corn, legume, cassava, yam, banana, plantain, palm fruit or rubber. The exact mix and amounts of these other crops are unknown but their economic value was defined and an economic allocation is applied to split the impacts among cocoa beans and other crops.

The shares of the different archetypes per country are described in Tab. 21.

Tab. 21: Cocoa production mixes in main producing countries

Country	Low-input farms	Medium-input farms	Extreme high-input farms	Agroforestry	Improved
Brazil	0%	48%	30%	22%	0%
Cameroon	37%	0%	0%	56%	7%
Ecuador	0%	52%	33%	15%	0%
Ghana	39%	0%	0%	36%	25%
Indonesia	0%	43%	39%	18%	0%
Ivory Coast	51%	0%	0%	36%	13%

For all systems and countries, the functional unit is 1 kg of cocoa beans, sun-dried, at the farm.

2.7.1 Specific modelling for cocoa from agroforestry systems

To enable to account for removals or not, depending on the needs of the user, two versions of the cocoa cultivation dataset are available, one considering the carbon storage in perennial biomass in tropical wet agroforestry systems, the other excluding it. According to Somarriba (2013) 2600 kg C are accumulated in aboveground biomass per year for cocoa agroforestry systems.

The biomass stock in aboveground biomass is constituted among others of timber wood (22.8 t C/ha), fruit trees (8.7 t C/ha) and cocoa trees (9 t C/ha) that are considered as rotating crops, hence not permanent. They correspond together to 40.5 t C/ha over the total of 49.2 t C/ha. Other trees are considered permanent (they add up to 8.7 t C/ha). The ratio between permanent and non-permanent trees is applied to the accumulation rate of 2600 kg C/ha-y, leading to a permanent storage of 1686 kg CO_2/ha-y modelled as fossil CO_2 (*carbon dioxide, land transformation*) and a non-permanent storage of 7848 kg CO_2/ha-y modelled as biogenic CO_2.

To consider agroforestry biodiversity services, the land occupation and transformation have been modelled as "forest, used" instead of "permanent crop".

2.8 Mushroom cultivation

Two types of mushroom are modelled: button mushrooms (*agaricus bisporus*) in the Netherlands and shiitake (*lentinula edodes*) in China.

For both types of mushrooms, the model considers different steps of the production system:

Substrate production in bags: the functional unit is 1 kg of substrate production and the reference flow is a bag of 19 kg substrate for the button mushroom and a bag of 2 kg substrate for the shiitake

Production of mycelium inoculum: the functional unit is 1 kg of mycelium production and the reference flow is a bag of 3 kg mycelium

Mushroom cultivation: the functional unit is 1 kg of fresh mushroom production

2.8.1 Button mushroom *Agaricus Bisporus* cultivation

For button mushrooms, most of the data are derived from three papers by F. J. Leiva (Leiva 2015a, Leiva 2015b, Leiva 2016) and correspond to production in Spain. The data were adapted to represent Dutch production by regionalizing the water flows and using a European average electricity mix.

Substrate is produced and packed in 19 kg packaging and mycelium preparation is produced and packed in 3 kg seeds. To produce 1 kg of fresh mushrooms, 3.4 kg of substrate is needed together with 77 g of mycelium

preparation. The mycelium is used to inoculate the substrate bags but the model separates these different elements and puts them together in the mushroom cultivation process.

The substrate production includes the inputs of materials that are composted to produce the substrate (straw, manure, gypsum, fertilisers, etc.), the energy and water used for the composting, pasteurization and packing, as well as the disinfectant. The packaging material is also included (plastic bags and pallet production and end-of-life), considering bags of 19 kg substrate. The direct emissions from the composting process are also considered. The material and energy needed are based on Leiva 2016, while the emissions from composting are based on Robinson 2018.

The production of mycelium to inoculate the compost substrate is modelled including the steps of rye substrate preparation (rye grain, lime, energy and water), the inoculum creation (petri dishes, chemicals, glucose, energy and water) and the mycelium preparation (energy and water). Packages of 3 kg seeds are considered but the packaging itself is neglected. There are also agar and malt growing medium that are not included because of a lack of data. All data regarding the mycelium inoculum production are based on Leiva 2015b. 0.144 kg of mycelium inoculum is needed for a bag of 19 kg compost.

The cultivation of the mushroom itself groups the inputs of substrate and mycelium, and the impacts related to the growing chambers (disinfection, soil covering (peat), temperature and humidity control (water and energy consumption)) and the cultivation process (water and pesticides). The direct emissions from peat degradation are included, while the the infrastructure and the packaging of finished products are excluded. The spent substrate is considered to be used in agricultural systems (cut-off). This cultivation process is mainly based on Leiva 2015a for the main inputs and outputs, on DAFM 2012 and Potocnik 2015 for the pesticides use and on Leiva 2015c and Robinson 2018 for the peat degradation emissions.

2.8.2 Shiitake mushroom *Lentinula Edodes* cultivation

The shiitake mushrooms are mainly based on Fan 2005, Leiva 2015a and Leiva 2015b. The datasets are representative for Chinese production considering Chinese electricity mix and regionalised water flows.

Substrate is produced and packed in 2 kg bags and mycelium preparation is produced and packed in 3 kg seeds. To produce 1 kg of fresh shiitake, 2.2 kg of substrate is needed together with 56 g of mycelium preparation. The mycelium is used to inoculate the substrate bags but the model separates these different elements and puts them together in the mushroom cultivation process. The production of 1 kg of fresh shiitake will give 100 g dried shiitake.

The production of 2 kg substrate bags is considered. This process includes the substrate material (saw dust, wheat bran, sugar and gypsum) used and the plastic bags (PP). The substrates are mixed together with water and put in bags. The bags are then sterilized in an autoclave. The machinery used and its energy consumption for these different steps is included (substrate mixing, bags filling, bags sealing, autoclave for sterilization). The machinery is assumed to be recycled at the end-of-life (cut-off). The substrate bags in plastic are considered to be landfilled at their end-of-life while the substrate itself is recovered and use in agriculture (cut-off). The landfilling is considered in this substrate dataset and not in the mushroom cultivation process. The substrate materials are based on Fan 2005, while the PP bags are based on bags found on www.alibaba.com and the machinery production and use based on www.oystermachinery.com and chesc.org[2].

The mycelium production is considered as the same as for the button mushroom, with electricity and water adapted to a Chinese context.

The cultivation process groups the production of the substrate bags, the production of the mycelium, and the growing process in growing chambers. The energy, water, disinfectant and pesticides are included. The infrastructure (except the inoculation machine) are excluded as well as the mushroom packaging. The inoculation machine is assumed to be recycled at its end-of-life. The substrate is assumed to be used in agricultural systems (cut-off approach). The substrate bags and the amount of mycelium inoculum are based on

[2]Bags: https://www.alibaba.com/product-detail/China-Spawn-Bag-Supplier-Mushroom-Growing_60791445905.html?spm=a2700.7724838.2017115.317.6e1fed5ddMH25c, accessed September 2018. Machinery: http://www.oystermachinery.com and https://chesc.org/wp-content/uploads/UCR-Autoclave-study-2016-PROCUREMENT-DF.pdf, accessed December 2018

Fan 2005. The growing chambers and growing process are adapted from Leiva 2015a that corresponds to button mushrooms cultivation because of a lack of data about shiitake mushrooms production. The covering soil from Leiva is excluded as no additional substrate is added for shiitake production in bags.

2.9 RSPO and non-RSPO palm fruit bunch cultivation

The RSPO and non-RSPO palm fruit bunch cultivation datasets are modelled based on Schmidt et al. 2015 and 2020 and following the WFLDB modelling guidelines. Their specificity is on the LUC and peatland degradation adaptation for the RSPO cultivation.

The LUC accounting method used by Schmidt et al. 2020 is different from the WFLDB sLUC standard. For this dataset, the WFLDB standard has been applied. However, the relative difference observed by Schmidt et al. 2020 between RSPO and non-RSPO has been applied.

In practice, the RSPO standard has prohibited the conversion of primary forest since 2005, and the conversion of secondary forest since 2018. It appears that a lot of deforestation has occurred under the RSPO label. This means that a meaningful adaptation of the LU loss mix would only apply at best on two years, because the end year of the available data for sLUC accounting is 2020. The relative difference observed by Schmidt et al. 2020 between RSPO and non-RSPO (about 10%) is considered to be a good representation of the LU loss mix adaptation.

Regarding peatland drainage emissions, a similar approach has been adopted. It is worth noticing that RSPO limits the depth of drainage since 2005, and completely prohibits new establishment of palm oil plantations on peatlands since 2018. This explains a larger relative difference observed by Schmidt et al. 2020 between RSPO and non-RSPO (about 60% reduction), which is considered for this dataset.

3 Animal production

Animal production systems are modelled in a systematic way that involves a core model, based on a GLEAM v2 (FAO 2018) farm archetype, and several modules (based on WFLDB Methodological Guidelines 3.9).

The approach adopted at farm level (Figure 2) doesn't distinguish cohorts of animals, i.e. these are not modelled separately (there is no feed basket, enteric emissions and manure management specific to adult females, replacement females, fattening males, etc.). However, the cohorts are precisely calculated based on GLEAM v2, and their feed intake, manure production and enteric emissions are known and summed up in the model.

This also implies that the new-born animals are known but not visible in the model. Similarly, the animals that are fattened on another site from the pregnancy and young age site (e.g. meat calves a few weeks after birth) are known but also not visible in the model. The herd structure is outlined as part of each dataset metadata.

Dairy farms are modelled slightly differently, as described in chapter 0. Their model follows a similar structure but is based on a different framework.

The following sections provide detailed information on the animal farm model (housing and feed basket), with key parameters. The emissions from animal systems (enteric methane, particulate matters) as well as the manure emissions are described in the WFLDB Methodological Guidelines 3.9.

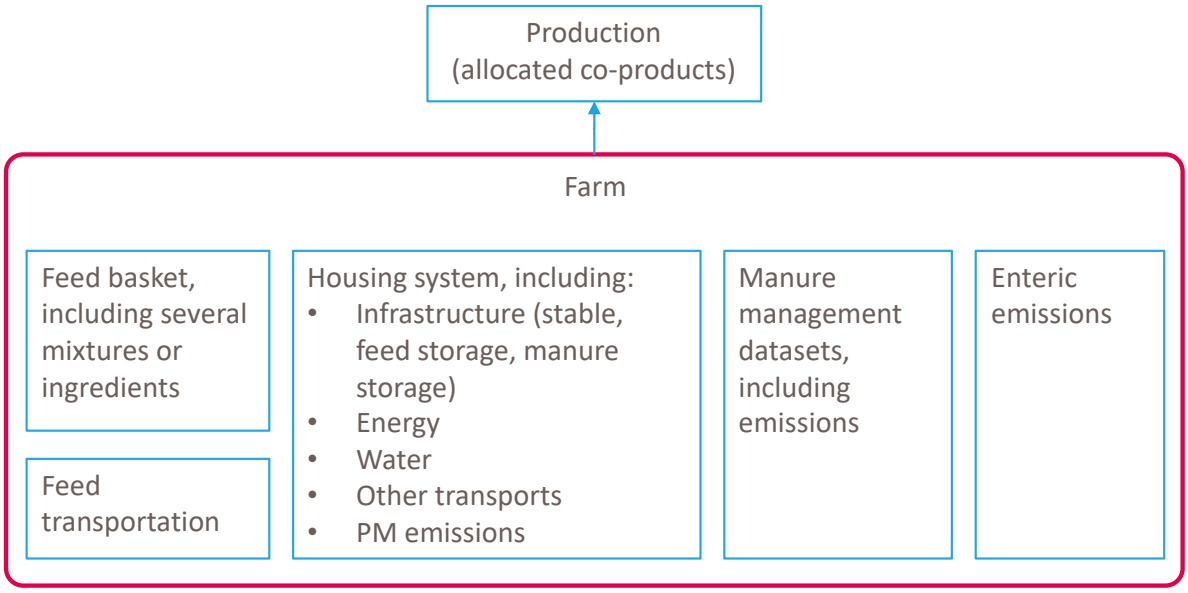


Figure 2: Farm model including the different modules

Note 1: for swine and sheep farms, the housing system is not a separated module but is integrated directly in the farm dataset.

Note 2: for beef cattle, feed storage has been separated from the housing system and has been grouped with feed transportation.

3.1 Manure management

Beside manure excreted on pasture, it is considered that all other manure is collected at the barn or the feedlot.

The nitrogen content in the manure is a key parameter to calculate the emissions. The adopted values are presented in Tab. 22.

Tab. 22: Nitrogen content of manure from different animals

Animal	N content in manure (g/kg DM)	Source
Dairy cows and supporting animals (altogether)	0.045	Nennich 2005
Beef cattle	0.049 (considered identical to dairy cows in the model)	Nennich 2005
Swine	0.070	Nennich 2005
Layer hen	0.073	Nennich 2005
Broiler and turkey	0.055	Nennich 2005
Sheep	0.034	Ogejo 2010

Six manure management systems are represented with up to three climate conditions (cool, temperate, warm) based on IPCC (2006). The adopted mix of manure management for each country and animal system is taken from IPCC (2019) from tables 10A.6 to 10A.9 for beef cattle, dairy cattle, poultry, laying hens, swine and sheep.

Data sources:

Nennich TD, Harrison JH, VanWieringen LM, et al (2005) Prediction of manure and nutrient excretion from dairy cattle. J Dairy Sci 88:3721–33. doi: 10.3168/jds.S0022-0302(05)73058-7

Ogejo JA, Wildeus S, Knight P, Wilke RB (2010) Technical Note: Estimating Goat and Sheep Manure Production and their Nutrient Contribution in the Chesapeake Bay Watershed. Appl Eng Agric 26:1061–1065. doi: 10.13031/2013.35912

3.2 Poultry

The animal live weight production for poultry is modelled following the chicken industrial production system that is described in GLEAM v2 (FAO 2018). All animal husbandry inputs, such as infrastructure, water, energy, are adjusted based on the datasets for broiler production modelled by Agroscope as part of WFLDB Phase One ('Broiler, live weight, at farm/BR U', 'Broiler chicks, at farm/GLO U', 'Hatching eggs, at hatchery/GLO U') and also on information retrieved from Dekker et al. (2011). The inputs of these datasets are merged and scaled based on total live weight production, in order to describe the overall broiler live weight production system.

Turkey production activities as well as feed intake are considered to be similar to the broiler industrial production system as it is described in GLEAM v2.

3.2.1 System description

The main system parameters for chicken broilers at farm are provided in Tab. 23 and in Tab. 24 for turkeys. Functional unit, reference flow and included process are as follows:

Functional unit: 1 kg of live weight of broiler (or turkey) at farm, ready for slaughtering.

Reference flow: 1 year of a poultry growing farm. The amount of total live weight produced per farm system and country is calculated with the GLEAM v2 model and is presented in Tab. 23. The data describe industrial broiler farm production systems.

The system boundaries include: feed for the overall poultry system (including for replacement animals) and its transport from the regional warehouse to the animal farm (for purchased feed, excluding grazed grass, if any),

other inputs related with husbandry such as infrastructure, water and energy, manure management emissions and direct enteric emissions from the animals.

Tab. 23: System parameters for broiler systems

Broiler	Brazil	Canada	China	Germany	Italy	Poland	United States
Average size of holding (heads)	10 000	48 934	9 996	21 391	11 401	324	2 000
Feed needed for the overall system for one year (kg DMI)	404 313	1 978 475	302 373	774 272	412 663	11 849	80 866
Total live weight (LW) produced in one year (kg)	162 842	793 244	113 711	292 944	156 130	4443	32 422
Share (fresh meat) on global export (absolute)	29%	1%	6%	3%	1%	4%	26%
Share (fresh meat) on global export (relative)	41.4%	1.43%	8.57%	4.29%	1.43%	5.71%	37.1%

Tab. 24: System parameters for turkey systems

Turkey systems	Poland	Germany
Average size of holding (heads)	122	3 122
Feed needed for the overall system for one year (kg DMI)	13 385	338 995
Total live weight (LW) produced in 1 year (kg)	5 019	128 258
Share (fresh meat) on global export (absolute) (FAOSTAT 2012-2016)	13%	10%
Share (fresh meat) on global export (relative)	56.5%	43.5%

Data sources:

Dekker SEM, de Boer IJM, Vermeij I, et al (2011) Ecological and economic evaluation of Dutch egg production systems. Livest Sci 139:109–121. doi: 10.1016/j.livsci.2011.03.011

3.2.2 Poultry feed baskets

Tab. 25 shows the feed components and the composition of the feed baskets for the different poultry (broiler and turkey) industrial systems. It refers to feed for broilers, which is considered to be the same as for turkeys. Regionalised feed mixes and ingredients are used when available.

The feed composition is extracted from GLEAM v2. Data are regionalised and refer to 1 kg DM intake for poultry industrial systems.

Tab. 25: Feed composition for poultry systems

Feed components	Poultry indust. system BR	Poultry indust. system CN	Poultry indust. system PL	Poultry indust. system RER	Poultry indust. system RNA
Feed additives, at regional warehouse, as DM	0.01	0.02	0.01	0.02	0.01
Fishmeal, as feed, for monogastric animals, at regional warehouse, as DM	0.05	0.01			0.05
Grains compound feed, for broiler, industrial poultry system, at regional warehouse, as DM (regionalised mix)	0.65	0.71	0.92	0.87	0.65
Limestone, as feed, for poultry, at regional warehouse, as DM (regionalised)	0.01	0.01	0.01	0.01	0.01
Oilseed meal mix, as feed, at regional warehouse, as DM (regionalised mix)	0.05	0.01	0.06	0.02	0.05
Protein mix compound feed, 100% soy, for monogastric animals, at regional warehouse, as DM	0.23	0.24		0.08	0.23
Grand Total (kg DM)	**1**	**1**	**1**	**1**	**1**

3.3 Swine

The animal live weight production for swine is modelled following the swine typologies as introduced by GLEAM v2 (FAO 2018). All animal husbandry inputs, such as infrastructure, water, energy, are adjusted based on the datasets for swine production modelled by Agroscope as part of WFLDB Phase One ('Swine, live weight, at farm/ES U', 'Piglet, for fattening, at farm/GLO U'). The inputs of the two datasets are merged and scaled based on total live weight production, in order to describe the overall swine live weight production system.

The swine archetypes that are considered correspond to the 3 production systems that are described in GLEAM v2, i.e. backyard system, industrial system and intermediate system. The average national mix for each country's swine production is a mix of the different archetypes, based on expert knowledge to match the national average yield and farm size distribution.

3.3.1 System description

The main system parameters for swine live weight production at farm are provided in Tab. 26. Functional unit, reference flow and included processes are as follows:

Functional unit: 1 kg of live weight of swine at farm, ready for slaughtering.

Reference flow: 1 year of a swine farm. The amount of total live weight produced per farm system and country is calculated with the GLEAM v2 model and is presented in Tab. 26.

The system boundaries include: feed for the overall swine system (including for replacement animals) and its transport from the regional warehouse to the animal farm (for purchased feed, excluding grazed grass, if any), other inputs related with animal husbandry such as infrastructure, water and energy, manure management emissions and direct enteric emissions from the animals.

Tab. 26: System parameters for swine

Swine		United States	Germany	Canada	Spain	Denmark	Poland	Italy
Average size of holding (heads)	**Backyard**	n.a.	20	20	20	20	5	8
	Industrial	1 161	584	5 000	530	4 000	150	800
	Intermediate	n.a.	200	260	70	140	20	85
Feed for the overall system for one year (kg DMI)	**Backyard**	n.a.	12 497	12 497	12 497	12 497	3 184	4 999
	Industrial	848 324	426 941	3 655 316	387 464	2 924 253	109 385	584 851
	Intermediate	n.a.	129 720	5703	45 402	91 255	13 099	55 405
Total live weight (LW) produced in one year (kg)	**Backyard**	n.a.	5 252	5 252	5 252	5 252	1 313	2 101
	Industrial	523 914	245 735	2 103 898	223 013	1 681 799	64 328	336 360
	Intermediate	n.a.	65 063	84 582	22 772	45 769	6538	27 788
Share in national mix	**Backyard**	0%	1%	1%	1%	1%	4%	1%
	Industrial	100%	98%	90%	97%	98%	76%	96%
	Intermediate	0%	1%	9%	2%	1%	20%	3%
	Data source:	estimate	(DAF, 2018)	(statcan, 2015)	(DAF, 2018)	(DAF, 2018)	(DAF, 2018)	(DAF, 2018)
Share (fresh meat) on global export (absolute) (FAOSTAT 2012-2016)		22%	16%	15%	10%	7%	2%	1%
Share (fresh meat) on global export (relative)		30.1%	21.9%	20.5%	13.7%	9.59%	2.74%	1.37%

3.3.2 Swine feed baskets

Tab. 27 shows the feed components and the composition of the feed baskets for the different swine systems, namely for backyard, industrial and intermediate systems. Regionalised feed mixes and ingredients are used when available.

The feed composition is extracted from GLEAM v2. Data are regionalised and refer to 1 kg DM intake for the different swine systems.

Tab. 27: Feed composition for swine systems

Feed components	Swine backyard system PL	Swine backyard system WEU	Swine industrial system PL	Swine industrial system US	Swine industrial system WEU	Swine interm. System PL	Swine interm. System WEU
Feed additives, at regional warehouse, as DM			0.02	0.02	0.02	0.01	0.01
Fishmeal, as feed, for monogastric animals, at regional warehouse, as DM			0.03	0.01	0.01	0.03	0.01
Grains compound feed, for swine, backyard system, at regional warehouse, as DM (regionalised mix)	0.33	0.41					
Grains compound feed, for swine, industrial system, at regional warehouse, as DM (regionalised mix)			0.64	0.81	0.63		
Grains compound feed, for swine, intermediate system, at						0.61	0.55

regional warehouse, as DM (regionalised mix)							
Molasses, as feed, at regional warehouse, as DM					0.02		0.02
Oilseed meal mix, as feed, at regional warehouse, as DM (regionalised mix)	0.21	0.07	0.1	0.01	0.11	0.1	0.09
Palm kernel cake, as feed, at regional warehouse, as DM					0.01		
Protein mix compound feed, 100% soy, for monogastric animals, at regional warehouse, as DM			0.15	0.11	0.15	0.11	0.16
Protein mix compound feed, 93% soy, for monogastric animals, at regional warehouse, as DM	0.09	0.14					
Pulses straw, as feed, at regional warehouse, as DM	0.03	0.04				0.02	0.02
Swill, as feed, for monogastric animals, at regional warehouse, as DM	0.2	0.15					0.02
Bran mix, as feed, at regional warehouse, as DM	0.14	0.19	0.06	0.04	0.05	0.12	0.12
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

3.4 Lamb

The animal live weight production for lamb is modelled following the small ruminants' typologies documented by GLEAM v2 (FAO 2018). All animal husbandry auxiliary inputs, such as infrastructure, water, energy, are adjusted based on the datasets for swine production from the AGRIBALYSE database (Koch and Salou 2015) ('Lamb, conventional, indoor production system, at farm gate/FR U', 'Lamb of 0 day, conventional, indoor production system (animal class), at farm gate/FR U'). The inputs of the two datasets are merged and scaled based on total live weight production, in order to describe the overall lamb live weight production system.

The lamb archetypes that are considered, are the two livestock production systems that are described in GLEAM v2, i.e. the mixed system and the grassland system. The average national mix for each country's lamb production is a mix of the different typologies, based on expert knowledge to match the national average yield and farm size distribution.

Lamb production is a multi-output process, with lamb, sheep (or ewe) and wool as co-products. No milk production from sheep is considered in the current model. The allocation between the 3 co-products is done based on Biophysical Allocation (BA) with protein content, following recommendations from Wiedemann et al. (2015) and Wiedemann et al. (2016), where this allocation key is suggested as the most appropriate for lamb systems. Protein content of 18% for live weight, hence for lamb and sheep, and 100% for wool (clean wool yield: 68%) are considered, and the amount of lamb, sheep and greasy wool are calculated with the GLEAM v2 model for each system.

3.4.1 System description

The main system parameters for lamb live weight production at farm are provided in Tab. 28. Functional unit, reference flow and included process are as follows:

Functional unit: 1 kg of live weight of lamb at farm, ready for slaughtering.

Reference flow: 1 year of a lamb farm. The amount of total live weight produced per farm system and country is calculated with the GLEAM v2 model and is presented in Tab. 28Tab. 39.

The system boundaries include: feed for the overall lamb system (including for replacement animals) and its transport from the regional warehouse to the animal farm (for purchased feed, excluding grazed grass, if any), other inputs related with animal husbandry such as infrastructure, water and energy, manure management emissions and direct enteric emissions from the animals.

Tab. 28: System parameters for lamb systems

Lamb		Australia	Canada	Ireland	New Zealand	United States
Average size of holding (heads)	**Mixed**	1 500	330	100	550	55
	Grassland	3 000	500	150	1 000	200
Feed for the overall system for one year (kg DMI)	**Mixed**	553 126	130 375	37 883	202 813	21 729
	Grassland	1 117 895	184 035	54 234	372 632	80 597
Total live weight lamb (LW) produced in one year (kg)	**Mixed**	41 857	7334	2434	15 347	1222
	Grassland	83 713	11 112	3651	27 904	4445
Share (lamb fresh meat) on global export (absolute) (FAOSTAT 2012-2016)		36%	0.02%	4%	35%	0.34%
Share (fresh meat) on global export (relative)		47.8%	0.03%	5.31%	46.4%	0.45%
Share in national mix	**Mixed**	10%	90%	20%	10%	90%
	Grassland	90%	10%	80%	90%	10%
	Data source	(Spruce, 2019)	(VCE, 2009)	(AgriLand, 2019)	(Spruce, 2019)	(USDA, 2017)

The allocation shares for the 3 co-products are calculated according to the holding size of each system and using the biophysical allocation key that is described in the previous the section. The results are given in Tab. 29. Their production amount is considered identical for mixed and for grassland production systems.

Tab. 29: Allocation shares for lamb co-products

Lamb		Australia	Canada	Ireland	New Zealand	United States
Mixed/ Grassland	Lamb (LW)	55%	56.3%	64.4%	55%	56.3%
	Wool (greasy)	36%	32.5%	19%	36%	32.5%
	Sheep (LW)	9%	11.2%	16.6%	9%	11.2%

Data sources:

Wiedemann SG, Ledgard SF, Henry BK, et al (2015) Application of life cycle assessment to sheep production systems: investigating co-production of wool and meat using case studies from major global producers. Int J Life Cycle Assess 20:463–476. doi: 10.1007/s11367-015-0849-z

Wiedemann SG, Yan M-J, Murphy CM (2016) Resource use and environmental impacts from Australian export lamb production: a life cycle assessment. Anim Prod Sci 56:1070. doi: 10.1071/AN14647

3.4.2 Lamb feed baskets

Tab. 30 shows the feed components and the composition of the feed baskets for the different lamb systems, namely for mixed and grassland systems. Regionalised feed mixes and ingredients are used when available.

The feed composition for the mixed system is extracted from GLEAM v2. Data are regionalised and refer to 1 kg DM intake for lamb mixed systems. The feed composition for the grassland system is based on the assumption that 90% of the total DM intake comes from fresh grazed grass on the field, and the partitioning of the remaining

10% is shared between hay and lupins in accordance with feed descriptions that are presented in Wiedemann et al. (2016).

Tab. 30: Feed composition of lamb systems

	Lamb mixed system IE	Lamb mixed system OCE	Lamb mixed system RNA	Lamb grassland system IE	Lamb grassland system OCE	Lamb grassland system RNA
Bran mix, as feed, at regional warehouse	0.03	0.05				
Crop residues, as feed, at farm, as DM	0.12	0.01				
Fodder beet, as feed, at regional warehouse, as DM	0.02					
Grains mix, as feed, at regional warehouse, as DM (regionalised mix)	0.01	0.02	0.17			
Grazed grass, on pasture (regionalised)	0.46	0.76	0.35	0.9	0.9	0.9
Hay, production mix, at farm, per kg DM (regionalised)	0.22	0.07	0.44	0.061	0.061	0.061
Legumes and silage, as feed, at farm, as DM	0.08					
Lupin seeds, as feed, at regional warehouse, as DM (regionalised mix)		0.09	0.03	0.039	0.039	0.039
Molasses, as feed, at regional warehouse, as DM	0.01					
Oilseed meal mix, as feed, at regional warehouse, as DM (regionalised mix)	0.02		0.01			
Sugar beet pulp, as feed, at regional warehouse, as DM	0.03					
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Data sources:

Wiedemann SG, Yan M-J, Murphy CM (2016) Resource use and environmental impacts from Australian export lamb production: a life cycle assessment. Anim Prod Sci 56:1070. doi: 10.1071/AN14647

3.5 Beef cattle

The animal live weight production for beef cattle is modelled following the cattle typologies given by GLEAM v2 (FAO 2018). Animal husbandry inputs, such as infrastructure, feed storage, water, energy, are adjusted based on the datasets for beef production modelled by Agroscope as part of WFLDB Phase One ('Beef cattle, from fattening non-grazing, live weight, at farm/AU U', 'Calf, dairy cow, at farm/GLO U'), or taken from Rotz et al. (2013) and Rotz et al. (2019). The inputs of the two datasets are merged and scaled based on total live weight production, in order to describe the overall beef live weight production system. Electricity consumption in a feedlot or intensive system is considered, as described at Rotz et al. (2013), and it is assumed that 30% less light time is given to the animals in husbandry in mixed, and 70% less light time in grassland systems, respectively.

The cattle archetypes that are considered, are the two livestock production systems that are described in GLEAM v2; the mixed and the grassland systems. The average national mix for each country's cattle production is a mix

of the different typologies, based on expert knowledge to match the national average yield and farm size distribution.

3.5.1 System description

The main system parameters for cattle at farm are provided in Tab. 31. Functional unit, reference flow and included process are as follows:

Functional unit: 1 kg of live weight of beef cattle at farm, ready for slaughtering.

Reference flow: 1 year of cattle fattening farm. The amount of total live weight produced per farm system and country is calculated with the GLEAM v2 model and is presented in Tab. 31.

The system boundaries include: feed for the overall beef system (including for replacement animals) and its transport from the regional warehouse to the animal farm (for purchased feed, excluding grazed grass, if any), other inputs related with animal husbandry such as infrastructure, animal feed storage, water and energy, manure management emissions and direct enteric emissions from the animals.

Tab. 31: System parameters for beef systems

Beef		Australia	Brazil	China	Germany	United Kingdom	India	United States
Average size of holding (heads)	Mixed	255	2 900	400	80	140	6.5	9
	Feedlot or intensive	5 000	8 000	2 000	500	2 000	50	5 000
	Grassland	300	5 000	50	60	100	20	12
Total live weight (LW) produced in 1 year (kg)	Mixed	69 329	304 784	35 515	16 214	28 374	577	2 447
	Feedlot or intensive	1 383 855	912 454	247 573	100 245	400 942	6191	1 383 855
	Grassland	81 564	525 490	4 439	12 160	20 267	1 776	3 263
Feed for the overall system for one year (t DMI)	Mixed	989	9 597	1149	258	495	22.0	34.9
	Feedlot or intensive	15 341	16 444	3927	1337	63 648	98.6	15 341
	Grassland	1 383	16 360	147	231	385	58.8	55 333
Share in national mix	Mixed	30%	40%	64%	40%	49%	90%	12%
	Feedlot or intensive	40%	10%	20%	30%	2%	10%	77%
	Grassland	30%	50%	16%	30%	49%	0%	11%
	Data source	(futurebeef, 2011)	(NEPcon, 2019)	(ScienceAdvances, 2018)	(arc2020, 2017)	(NBA, 2017) (Guardian, 2018) (AHDB, 2018)	(Wire, 2017)	(GAO, 2008)

Data sources:

Rotz CA, Isenberg BJ, Stackhouse-Lawson KR, Pollak EJ (2013) A simulation-based approach for evaluating and comparing the environmental footprints of beef production systems. J Anim Sci 91:5427–5437. doi: 10.2527/jas.2013-6506

Rotz CA, Asem-Hiablie S, Place S, Thoma G (2019) Environmental footprints of beef cattle production in the United States. Agric Syst 169:1–13. doi: 10.1016/j.agsy.2018.11.005, supplementary information for cow-calf system.

3.5.2 Cattle feed baskets

Tab. 32, Tab. 33 and Tab. 34 show the feed components and the used background datasets for beef feedlot or intensive, mixed and grassland systems respectively per country. Regionalised feed mixes and ingredients are used when available.

The feed composition for the mixed system is extracted from GLEAM v2. Data are regionalised and refer to 1 kg DM intake for beef feedlot or intensive and mixed systems. The feed composition for the grassland system is based on the assumption that 92.7% of the total DM intake comes from fresh grazed grass on the field, and 7.3% comes from hay, following the pasture-based diet that is described in Pelletier et al. (2010).

Tab. 32: Feed composition of beef feedlot or intensive systems

Feed components	Beef feedlot or intensive system BR	Beef feedlot or intensive system CN	Beef feedlot or intensive system IN	Beef feedlot or intensive system RER	Beef feedlot or intensive system US
Bran mix, as feed, at regional warehouse, as DM	0.03	0.03	0.03		
Crop residues, as feed, at farm, as DM	0	0.14	0.14		
Grains mix, as feed, at regional warehouse (regionalised)	0.62	0.28	0.28		0.73
Grains mix, as feed, at regional warehouse, as DM (regionalised mix)				0.73	
Grazed grass, on pasture (regionalised)	0.01	0.01	0.01		
Hay, production mix, at farm, per kg DM (regionalised)	0.03			0.07	0.01
Legumes and silage, as feed, at farm, as DM	0.14	0.26	0.26	0.05	0.24
Molasses, as feed, at regional warehouse	0.03	0.01	0.01		
Oilseed meal mix, as feed, at regional warehouse, as DM (regionalised mix)	0.1	0.05	0.05	0.15	0.02
Wet distillers grains and solubles, as feed, at regional warehouse, as DM	0.04	0.22	0.22		
Grand Total	**1**	**1**	**1**	**1**	**1**

Tab. 33: Feed composition for beef mixed systems

Feed components	Beef mixed system BR	Beef mixed system CN	Beef mixed system IN	Beef mixed system RER	Beef mixed system US
Bran mix, as feed, at regional warehouse, as DM	0.03	0.03	0.02	0.03	0.01
Crop residues, as feed, at farm, as DM	0.08	0.29	0.45	0.03	
Grains mix, as feed, at regional warehouse (regionalised)	0.04	0.03		0.07	0.22
Grains mix, as feed, at regional warehouse, as DM (regionalised mix)	0.01			0.01	
Grazed grass, on pasture (regionalised)	0.5	0.15	0.04	0.42	0.32
Hay, production mix, at farm, per kg DM (regionalised)	0.13	0.23	0.26	0.15	0.33
Leaves, as feed, at farm, as DM	0.08	0.05	0.14		
Legumes and silage, as feed, at farm, as DM	0.09	0.17	0.05	0.22	0.11
Molasses, as feed, at regional warehouse	0.01		0.01	0.01	
Oilseed meal mix, as feed, at regional warehouse, as DM (regionalised mix)	0.01	0.02	0.01	0.04	0.01

Sugar beet pulp, as feed, at regional warehouse, as DM				0.02	
Sugarcane tops, as feed, at farm, as DM	0.02	0.01	0.02		
Wet distillers grains and solubles, as feed, at regional warehouse, as DM		0.02			
Grand Total	**1**	**1**	**1**	**1**	**1**

Tab. 34: Feed components for beef grassland systems

Feed components	Beef grassland system BR	Beef grassland system CN	Beef grassland system DE	Beef grassland system GB	Beef grassland system IN	Beef grassland system US
Grazed grass, on pasture (regionalised)	0.93	0.93	0.93	0.93	0.93	0.93
Hay, production mix, at farm, per kg DM (regionalised)	0.07	0.07	0.07	0.07	0.07	0.07
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**

Data sources:

Pelletier N, Pirog R, Rasmussen R (2010) Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agric Syst 103:380–389. doi: 10.1016/j.agsy.2010.03.009

3.6 Fresh meat at slaughterhouse

3.6.1 Included process for slaughtering

Transport of animal from farm to slaughterhouse (200 km assumed)

Slaughtering

- energy carriers
- tap water
- packaging film
- chemicals: acid and alkaline foam cleaning agents, and disinfectant
- slaughterhouse and infrastructure
- waste treatment (e.g. sewage, disposal bio-waste)

Multi-output dataset (several co-products from slaughtering considered), economic allocation is applied

The slaughterhouse datasets are named as follows:

- Slaughtering, beef cattle (WFLDB)/GLO U
- Slaughtering, poultry (WFLDB)/GLO U
- Slaughtering, swine (WFLDB)/GLO U

The slaughtering system description for beef cattle is considered to be a fair representation of the lamb slaughtering activity.

3.6.2 Allocation at slaughterhouse

Slaughtering is a typical multi-output process. In line with ISO 14040/ ISO 14044 economic allocation should be applied because

- the slaughtering process cannot be divided in separate sub-process

- there are no products that could replace the co-products of slaughtering
- the product and the co-products don't have a similar function

For pork, beef, lamb and chicken systems, economic allocation is applied based on the PEFCR Guidance 6.3 (EC-JRC 2017) for beef and lamb, and 2014-2015 data from the European Fat Processors and Renderers Association (http://www.efpra.eu/), as shown in Tab. 35.

Tab. 35: Animal meat products and coproducts allocation at slaughterhouse

	Product and co-products (kg)				Allocation factor (percentage of total revenue)			
	Pork	**Beef**	**Chicken and turkey**	**Lamb**	**Pork**	**Beef**	**Chicken and turkey**	**Lamb**
Fresh meat	0.54	0.46	0.62	0.44	94.2%	92.3%	95.9%	97.8%
Food grade offal	0.04	0.03	0.08	0.00	1.51%	0.6%	3.3%	0%
Food grade bones	0.11	0.08	0.00	0.04	1.35%	1.0%	0%	0.01%
Food grade fat	0.03	0.07	0.00	0.06	0.85%	1.8%	0%	0.02%
Food grade rind	0.03	0.00	0.00	0.00	1.4%	0%	0%	0%
Food grade blood	0.02	0.00	0.00	0.00	0.3%	0%	0%	0%
Cat. 3 slaughter by-products	0.18	0.07[a]	0.22	0.13	0.42%	0.8%[a]	0.7%	0.62%
Hides and skins	0.00	0.07	0.00	0.14	0%	3.5%	0%	1.6%
Feathers	0.00	0.00	0.06	0.00	0%	0%	0.06%	0%
Cat. 1/2 materials and waste	0.05	0.22	0.02	0.19	0%	0%	0%	0%
TOTAL	1.00	1.00	1.00	1.00	100%	100%	100%	100%

[a] includes rind and blood

Data sources:

- PEFCR Guidance 6.3 (EC-JRC 2017)
- European Fat Processors and Renderers Association: http://www.efpra.eu/

3.7 Chicken eggs

The chicken eggs production at farm is modelled following the laying hens system description that is given by GLEAM v2 (FAO 2018). Animal husbandry inputs, such as infrastructure, water, energy, are adjusted based on the datasets for laying and rearing hens production from datasets modelled by Agroscope as part of WFLDB Phase One ('Laying hen, in barn single tiered, at farm/CN U', 'Rearing hen, at farm/CN U') and also the barn system description documented in Dekker et al. (2011). The inputs of the two datasets are merged and scaled based on one laying round of 406 days and one rearing round of 119 days, respectively.

3.7.1 System description

The main system parameters for chicken egg production at farm are provided in Tab. 36. Functional unit, reference flow and included processes are as follows:

Functional unit: 1 kg of chicken egg at farm

Reference flow: The total weight of chicken eggs laid in an industrial laying flock over 1 year. The amount of total eggs produced per country is calculated with the GLEAM v2 model and is presented in Tab. 36.

The system boundaries include: feed for the overall chicken egg flock system (including for replacement animals) and its transport from the regional warehouse to the animal farm (for purchased feed, excluding grazed grass, if any), other inputs related with animal husbandry such as infrastructure, animal feed storage, water and energy, manure management emissions and direct enteric emissions from the animals.

Tab. 36: System parameters for chicken egg system

Chicken egg	Canada	China	Germany	Italy	Netherlands	Poland	Turkey
Average size of holding (heads)	36 590	19 789	665	2 760	17 284	71	29 985
Feed needed for the overall system for one year (kg DMI)	1 261 458	983 013	27 919	154 725	725 737	3 235	1 259 032
Total amount of eggs produced in 1 year (number)	310	219	339	339	339	285	339
Egg weight (g)	54	53	57	57	57	57	57
Share (fresh meat) on global export (absolute) (FAOSTAT 2012-2016)	0.2%	5%	7%	1%	21%	11%	13%
Share (fresh meat) on global export (relative)	0.34%	8.59%	12%	1.72%	36.1%	18.9%	22.3%

Data sources:

- Dekker SEM, de Boer IJM, Vermeij I, et al (2011) Ecological and economic evaluation of Dutch egg production systems. Livest Sci 139:109–121. doi: 10.1016/j.livsci.2011.03.011

3.7.2 Feed baskets for laying hen

Tab. 37 shows the feed components and the used background datasets for feeding laying hens per region or country. Regionalised feed mixes and ingredients are used when available.

Tab. 37: Feed components for laying hens

Laying hens	Poultry industrial laying system CN	Poultry industrial laying system PL	Poultry industrial laying system RER	Poultry industrial laying system RNA
Bran mix, as feed, at regional warehouse, as DM	0.06		0.01	
Feed additives, at regional warehouse, as DM	0.01	0.01	0.01	0.01
Fishmeal, as feed, for monogastric animals, at regional warehouse, as DM	0	0.03		
Grains compound feed, for layer hen, industrial poultry system, at regional warehouse, as DM (regionalised mix)	0.77	0.81	0.9	0.69
Limestone, as feed, for poultry, at regional warehouse, as DM (regionalised)	0.08	0.07	0.07	0.08
Oilseed meal mix, as feed, at regional warehouse, as DM (regionalised mix)	0.04	0.03		
Protein mix compound feed, 100% soy, for monogastric animals, at regional warehouse, as DM	0.04	0.05	0.01	0.22
Grand Total	**1**	**1**	**1**	**1**

3.8 Insect production

3.8.1 Crickets

Cricket production results in two products: Cricket, at plant (WFLDB)/TH U and Biofertiliser, from cricket production, at plant (WFLDB)/TH U

The reference flow is the production 36’741 kg of edible mass of cricket (*Gryllus bimaculatus* De Geer (field cricket) and *Acheta domesticus* (house cricket)), wet weight. Production in north-eastern Thailand based on Halloran et al 2017.

Biofertiliser is a co-product of cricket production. The total annual quantity of biofertiliser generated on the cricket farm was 26'414.5 kg. Biofertiliser consisted of cricket frass (excrement) in addition to any matter that falls to the floor of the cage, including wings, body parts, pumpkin seeds/stems, rice husks, pests, particles of uneaten feed, dust, shredded egg carton etc. It is assumed to have no economic value.

The system boundaries of the production system considered the entire production cycle of edible crickets as well as processing. It is representative of a medium scale production with a total annual cricket yield (*G. bimaculatus* and *A. domesticus*) on the farm was 36’741 kg (17’636 kg and 19’105 kg respectively, wet weight). The average life cycles of *G. bimaculatus* and *A. domesticus* were estimated as 42 and 49 days respectively. The farm produced approximately 8.5 cycles of crickets per year. Primary data (input materials as feed, energy use, output products and waste) were collected at farm level and reported in the publication Halloran (2017).

Data sources:

- Halloran A, Hanboonsong Y, Roos N, Bruun S (2017). Life cycle assessment of cricket farming in north-eastern Thailand, Journal of Cleaner Production, Vol 156.

3.8.2 Mealworms

Datasets covering products derived from mealworm are based on primary data provided by the company Ynsect. Two processes are covered:

Mealworm clean fresh larvae production (resulting in two products: Mealworm clean fresh larvae, at plant (WFLDB)/GLO U and Manure, from mealworm clean fresh larvae production, at plant (WFLDB)/GLO U)

Dried defatted mealworm protein production (resulting in two products: Dried defatted mealworm protein, at plant (WFLDB)/GLO U and Oil, from dried defatted mealworm protein production, at plant (WFLDB)/GLO U)

3.8.2.1 Mealworm clean fresh larvae

The functional unit is the production of 1 kg of mealworm (*Tenebrio molitor*) clean fresh larvae produced globally (data is based on a plant in France). It is based on inventory data from a mealworm protein producing company for a standardized production of 20’000 t defatted mealworm protein (volumetric base case for this industry).

An economic allocation is used for the clean fresh larvae coproducts. The economic allocation factors are based on confidential data:

- Mealworm clean fresh larvae: 87%
- Manure from clean fresh larvae production: 13%

This process focuses on the production of clean fresh larvae production, which is the first step before processing to produce defatted mealworm protein. Mealworms have a short biological life cycle. Li et al. (2013) report that egg incubation lasts 3 to 9 days, the larval stage lasts 26 to 76 days, the nymph stage lasts 3 to 12 days, and the pupal stage lasts 5 to 17 days. They are reared on a feeding substrate in plastic trays. Larvae for commercial purposes are harvested at the pre-pupal stage because they begin to lose weight after this stage. At harvest time, 90% of the larvae are processed, while 10% are used for reproduction, in which the larvae transform into nymphs and then adults over a few weeks. The rearing room is maintained at 26°C (between 20 and 30° C) and 65% relative humidity via dynamic ventilation and a cooling system. Larvae are fed mainly with wheat bran and wheat middlings. Key inventory data is summarised in the following table.

Tab. 38: Key inventory data for mealworm clean fresh larvae production

Co-products			**Comments**
Mealworm clean fresh larvae	1	kg	Economic allocation value: 87%
Manure from clean fresh larvae production	1.3	kg	Economic allocation value: 13%
Insects feed and gel			**Comments**
Wheat bran	1.6	kg / kg clean fresh larvae (CFL)	+ transport over 200 km
Wheat middlings	1.7	kg / kg CFL	+ transport over 200 km
Gel (99% water, 0.8% gelling agent (xanthan gum and carob) and 0.2% sorbate)	0.4	kg / kg CFL	+ transport over 200 km
Other inputs			**Comments**
Electricity	0.79	kWh/ kg CFL	Overall 4.21 kWh/ kg mealworm protein. 75 % of overall electricity
Steam	0.15	kg/ kg CFL	In ecoinvent: the energy content of steam is 2.75 MJ/ kg = 0.76 kWh / kg. We have thus 3.9 kg steam / kg. Overall 2.98 kWh / kg mealworm protein. 15% of overall steam
Tap water	5.5	L/ kg CFL	Overall 24.4 L/kg mealworm protein. 90% of overall water needs
Oxygen	2.4	Kg/kg CFL	Oxygen (natural resource input) for breathing (included for mass balance)
Emissions/wastes			**Comments**
Biogenic CO_2 to air	3.3	kg CO_2 / kg CFL	Biogenic CO2 with a GWP of 0 kg CO2 eq / kg
Water to air	4.4	kg / kg CFL	Fraction of tap water evaporated, steam, larvae water evapotranspiration
Wastewater	1.65	kg / kg CFL	Fraction of tap water not evaporated
Biowaste	0.1	kg/ kg CFL	Biowaste from mealworm production: 0.1 kg dead insects per kg larvae

3.8.2.2 Dried defatted mealworm protein

The mealworm clean fresh larvae can then be processed to produce dried defatted mealworm protein. This dataset is based on inventory data from a mealworm protein producing company for a standardized production of 20’000 t mealworm flour (volumetric base case for this industry).

For the different defatted mealworm protein coproducts, the economic allocation factors are based on confidential data:

- Dried defatted mealworm protein: 91%
- Oil from dried defatted mealworm protein: 9%

When mealworm larvae reach mealworm mature stage, they are steamed, sterilized, and processed (thermos mechanical processes + drying) into premium proteins and oils, without any chemical agents.

Key inventory data is summarised in the following table.

Tab. 39: Key inventory data for dried defatted mealworm protein production

Co-products			Comments
Dried defatted mealworm protein	1	kg	Economic allocation value: 91%
Oil from dried defatted mealworm protein	0.28	kg	Economic allocation value: 9%
Inputs			**Comments**
Clean fresh larvae	4	kg clean fresh larvae / kg mealworm protein	
Electricity	1.05	kWh/ kg mealworm protein	Overall 4.21 kWh/ kg mealworm protein. 25 % of overall electricity for mealworm protein
Steam	3.3	kg steam/ kg de mealworm protein	In ecoinvent: the energy content of steam is 2.75 MJ/ kg = 0.76 kWh / kg. We have thus 3.9 kg steam / kg. Overall 2.98 kWh / kg mealworm protein. 85% of overall steam for mealworm protein
Natural gas	1.38E-3	kWh/ kg mealworm protein	No double counting with steam
Tap water	2.44	L/ kg mealworm protein	Overall 24.4 L/kg mealworm protein. 10% of overall water needs
Sodium hydroxide	7.75E-4	L/ kg mealworm protein	
Emissions of water to air	6.02	Kg/kg mealworm protein	Water evaporation from steam and water evaporation from larvae drying
Wastewater	2.44	L/ kg mealworm protein	Overall 29.1 L/ kg mealworm protein sent to municipal wastewater treatment. 10% of overall wastewater for mealworm protein

Data sources: Data provided by the company Ynsect.

3.9 Soybean markets for feed

Soybean supply markets are generated for various countries or regions. They are established combining import statistics from UN Comtrade database (comtrade.un.org/data/, average 2016-2020) and the local production volume versus imported volume per country from FAOSTAT (www.fao.org/faostat/en/#data/SC, average 2014-2018).

For the regions, Canada and USA are summed both for imports from UN Comtrade database and fraction of own production and imports from FAOstat to obtain the RNA supply market.

The RLA supply market considered the following countries for the share of own production and imports based on FAOSTAT data: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Paraguay, Peru, Uruguay and Venezuela. For the import mix based on UN Comtrade database, the following countries are included: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, and Uruguay. The countries selected differ slightly because not all of them are available or have data in these 2 different databases.

For RAS supply market, the countries considered in FAOSTAT are Afghanistan, Armeina, Bangladesh, Cambodia, China, Cyprus, India, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Laos, Lebanon, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Oman, Pakistan, Philippines, Saudi Arabia, Sri Lanka, Tajikistan, Thailand, Timor-Leste, Turkmenistan, UAE, Uzbekistan, Vietnam and Yemen. Among them, the countries corresponding to more at least 1% of the total imports are selected and are then considered for the set of countries for the import origins from the UN Comtrade database: China, Indonesia, Iran, Japan, Malaysia, Pakistan, Saudi Arabia, Thailand, and Vietnam.

For RER, the supply mix is based on a publication of Rabobank (Rabobank, 2017).

For all soybean market mixes, the existing soy cultivation origins are then used to build the soy supply mix. When a specific origin country is not existing, a proxy or the global soybean is considered. The supply mix markets also contain transports to the market, considering the main production regions, transport by truck up to the closest harbour, transport by ship up to a typical harbour for the market and then a default truck transport to the regional storehouse.

Tab. 40: Soybean market mixes

	Brazil	China	India	USA	RAS	RER	RLA	RNA
Argentina	0%	6.2%	0%	0.3%	5.3%	37%	29%	0.2%
Benin	0%	0%	0.2%	0%	0%	0%	0%	0%
Bolivia	0%	0%	0%	0%	0%	0%	1.6%	0%
Brazil	99%	53%	0%	0%	47%	37%	56%	0%
Canada	0%	1.5%	0%	0.6%	0%	2.6%	0%	6.0%
China	0%	13%	0%	0%	11%	0%	0%	0%
Ethiopia	0%	0%	0.3%	0%	0%	0%	0%	0%
France	0%	0%	0%	0%	0%	0.8%	0%	0%
Indonesia	0%	0%	0%	0%	0.7%	0%	0%	0%
India	0%	0%	99%	0.3%	9.5%	0%	0%	0%
Italy	0%	0%	0%	0%	0%	2.4%	0%	0%
Paraguay	0.8%	0%	0%	0%	0%	7.1%	9.2%	0%
Romania	0%	0%	0%	0%	0%	0.7%	0%	0%
Serbia	0%	0%	0%	0%	0%	1.2%	0%	0%
Russia	0%	0.6%	0%	0%	0%	0%	0%	0%
Togo	0%	0%	0.1%	0%	0%	0%	0%	0%
Turkey	0%	0%	0%	0.2%	0%	0%	0%	0%
Urkaine	0%	0%	0%	0.1%	0%	1.3%	0%	0%
USA	0%	24%	0%	98%	27%	9.2%	3.5%	94%
Uruguay	0.1%	1.7%	0%	0%	0%	0%	1.4%	0%

Data sources:

- UN comtrade database: comtrade.un.org/data/
- FAOSTAT database: www.fao.org/faostat/en/#data/SC
- Rabobank 2017: research.rabobank.com/far/en/sectors/grains-oilseeds/the_european_feed_mix.html
- Ship distances: sea-distances.org
- Truck distances: maps.google.com

4 Milk production

4.1 System description

Country-specific datasets for raw milk at the farm are modelled as a combination of the following modules:

- A combination of archetypes of milk production systems
- A set of emission modules from different manure management systems
- Mechanised or non-mechanised farm management activities

Thirty-three archetypes (or typologies) of milk production systems were created. They describe how cows are fed and held at the farm, representing a selection of the diversity of dairy systems around the World. Production systems are characterised by their size (i.e. number of lactating cows) and different feeding patterns (i.e. grazing or non-grazing; proportions of hay, grains and compound feed in rations). The production system influences the milk yield and the milk-to-meat ratio (or BMR) (Tab. 41 to Tab. 43)). The amount of milk produced is then corrected to a standard of 4% fat and 3.3% protein equivalent, according to the International Dairy Federation (IDF 2015) formula for fat and protein corrected milk (FPCM). Most archetypes (thirty-one) are modelled based on the IFCN "typical farms", characterised in a global study on dairy systems from The Food and Agriculture Organisation of the United Nations (FAO), the International Dairy Federation (IDF) and the IFCN Dairy Research Network (FAO, IDF, IFCN 2014).

Archetypes are then combined as to represent the typical mix of dairy systems in different countries (Tab. 41). Two archetypes are created based on the same framework but represent farm types that were not described in the global study. They were necessary to balance the national mixes.

In parallel, emission modules for different manure management systems, as described in the WFLDB Methodological Guidelines 3.9 are used in the model. They are applied to the manure collected at barn only. The manure emissions occurring on pasture are accounted for in the grazed grass dataset.

All dairy farming modules generate milk as main product as well as live animals for slaughter or further fattening (i.e. culled cows and male calves) as co-products. The biophysical allocation formula from IDF (2015) is applied (see WFLDB Methodological Guidelines 3.5 for more details).

4.2 Dairy farm archetypes

Archetypes are representative of dairy farms where the male calves are not kept longer than one week and are sold for raising and for meat production as soon as possible. Female calves are only kept for sustaining the herd and any surplus is sold together with male calves[3].

Hence, for each dairy cow, a certain number of heifers are raised as future dairy cows and are part of the system. Also, dairy cows produce milk through lactation cycles (i.e. after each birth), so it is estimated that dairy cows are lactating about 4/5th of the time and are dry 1/5th of the time (there is a specific value for each archetype). After a few lactation cycles, dairy cows are not productive enough (i.e. culled cows) and are sold for slaughter or further fattening, then replaced in the herd by a newly grown heifer.

Because the system produces both milk and live animals (referred to as "meat"), an allocation is used between these co-products. Allocation based on physical causality (so-called "biophysical approach") is applied, following the guidelines from the International Dairy Federation (IDF 2015).

The FAO, IDF, IFCN 2014 report has been used as the main source to build the archetypes that are modelled for the WFLDB. There are 33 archetypes presented in the following tables. Several of them exist in more than one

[3] In the present state of the work, our model does not consider the cases where heifers are sold to other farms. By default, it means that it assumes an average of around 2 lactations per cow, hence one male calf (sold) and one female calf (for replacement). This gives place to a slight inaccuracy in less intensive cases, where more lactations can occur. The main reason for that is that the data source we are using (FAO, IDF, IFCN - 2014 - World Mapping of Animal Feeding Systems in the Dairy Sector) does not provide such level of details on the herd structure and number of lactations per farm type. This is a known limitation and will be improved in future release using LEAP data.

regionalised version, when they are used in countries of different regions; this explains why there are 42 archetype datasets in the database.

Tab. 41: Herd structure and milk production for WFLDB dairy farm archetypes

IFCN "typical farm"	Breed	(Dairy cows = 100%)		Heifers > 1	Heifers < 1	Total	Milk production (kg per year.cow)
		Lactating cows	Dry cows				
AT-14	Brown Swiss	11.8	2.2	5.3	5.4	24.7	**6204**
AU-275WA	HF	231.0	43.9	104.0	106.3	485.2	**7055**
BE-45	HF	37.8	7.2	17.0	17.4	79.4	**7663**
BR-20S	HF	16.8	3.2	7.6	7.7	35.3	**3980**
CA-58	HF	48.7	9.3	21.9	22.4	102.3	**7273**
CH-22	Brown Swiss	18.5	3.5	8.3	8.5	38.8	**6305**
CL-47	HF & HF x Jersey	39.5	7.5	17.8	18.2	82.9	**4820**
CN-17N	HF	14.3	2.7	6.4	6.6	30.0	**4653**
CZ-80	HF	67.2	12.8	30.3	30.9	141.1	**9201**
DE-31S	Simmental	26.0	4.9	11.7	12.0	54.7	**6576**
DE-90N	HF	75.6	14.4	34.0	34.8	158.8	**8165**
DK-125	HF	105.0	20.0	47.3	48.3	220.5	**9352**
ES-50NW	HF	42.0	8.0	18.9	19.3	88.2	**9328**
FI-25	Ayrshire and HF	21.0	4.0	9.5	9.7	44.1	**8191**
FR-50-W	HF	42.0	8.0	18.9	19.3	88.2	**7470**
ID-3NG	HF	2.3	0.7	1.1	1.1	5.1	**2707**
IE-48	HF	40.3	7.7	18.2	18.6	84.7	**7000**
IN-3E	Jersey cross-breed	2.0	1.0	1.0	1.0	5.0	**1390**
IN-3S	HF cross- breed	2.3	0.7	1.1	1.1	5.1	**2939**
IT-154	HF	129.4	24.6	58.2	59.5	271.7	**8810**
LowEuro-5 (*)	HF and local breed	4.2	0.8	1.9	1.9	8.8	**2000**
LowTropical-10 (*)	Jersey cross-breed	7.5	2.5	3.5	3.5	17.1	**700**
MX-20	HF	16.8	3.2	7.6	7.7	35.3	**4810**
NL-70	HF	58.8	11.2	26.5	27.1	123.5	**8416**
NZ-351	Cross-bred HF and Jersey	295.0	56.0	132.7	135.7	619.4	**4600**
PE-7	Brown Swiss	5.3	1.7	2.5	2.5	11.9	**2360**
PL-15	HF and local breed	12.6	2.4	5.7	5.8	26.5	**6826**
PY-45	HF	37.8	7.2	17.0	17.4	79.4	**3827**
RU-900	Ayrshire	756.0	143.7	340.3	347.9	1587.9	**5600**
SE-60	HF	50.4	9.6	22.7	23.2	105.9	**9805**
UK-149NW	HF	125.2	23.8	56.3	57.6	262.9	**7784**
US-2218NY	HF	1895.7	322.3	834.1	853.1	3905.2	**10610**
US-80WI	HF	67.2	12.8	30.3	30.9	141.1	**8963**

(*) Archetypes created in addition to those of the global study (FAO, IDF, IFCN 2014).

Tab. 42: Milk production, BMR and allocation to milk for WFLDB dairy farm archetypes

IFCN	kg FPCM / kg raw milk	Allocation to milk

"typical farm"	Milk production (kg per year.cow)	BMR ratio (M_{meat}/M_{milk})		
AT-14	6204	0.0236	1.0095	**85.7%**
AU-275WA	7055	0.0230	1.0753	**86.1%**
BE-45	7663	0.0248	0.9857	**85.0%**
BR-20S	3980	0.0337	1.0019	**79.6%**
CA-58	7273	0.0255	1.0095	**84.6%**
CH-22	6305	0.0232	1.0095	**86.0%**
CL-47	4820	0.0304	1.0095	**81.6%**
CN-17N	4653	0.0343	1.0095	**79.3%**
CZ-80	9201	0.0216	0.9424	**86.9%**
DE-31S	6576	0.0266	0.9976	**83.9%**
DE-90N	8165	0.0292	1.0095	**82.4%**
DK-125	9352	0.0197	1.0170	**88.1%**
ES-50NW	9328	0.0218	0.9230	**86.8%**
FI-25	8191	0.0207	1.0289	**87.5%**
FR-50-W	7470	0.0321	1.0019	**80.6%**
ID-3NG	2707	0.0386	1.0809	**76.7%**
IE-48	7000	0.0265	1.0095	**84.0%**
IN-3E	1390	0.0555	1.0809	**66.5%**
IN-3S	2939	0.0277	1.0809	**83.2%**
IT-154	8810	0.0192	1.0289	**88.4%**
LowEuro-5	2000	0.0732	1.0095	**55.8%**
LowTropical-10	700	0.0723	1.0095	**56.3%**
MX-20	4810	0.0307	1.0019	**81.5%**
NL-70	8416	0.0217	1.0289	**86.9%**
NZ-351	4600	0.0341	1.0753	**79.4%**
PE-7	2360	0.0543	0.9900	**67.2%**
PL-15	6826	0.0283	0.9706	**82.9%**
PY-45	3827	0.0348	1.0095	**79.0%**
RU-900	5600	0.0308	1.0095	**81.4%**
SE-60	9805	0.0187	1.0214	**88.7%**
UK-149NW	7784	0.0246	0.9781	**85.1%**
US-2218NY	10610	0.0212	0.9900	**87.2%**
US-80WI	8963	0.0207	1.0095	**87.5%**

(*) Archetypes created in addition to those of the global study (FAO, IDF, IFCN 2014).

Tab. 43: Daily feed intake of lactating cows for WFLDB dairy farm archetypes

IFCN	Pasture alone (no protein)	Hay, silage, haylage,	Daily feed intake

"typical farm"		Pasture with daily ration of protein	agricultural residues	Grain / non-processed concentrate	Compound feed / processed concentrate	(kg DMI / day.cow)
AT-14	0%	0%	84%	0%	16%	**23**
AU-275WA	50%	9%	9%	0%	32%	**18**
BE-45	0%	2%	77%	0%	21%	**22**
BR-20S	0%	65%	17%	1%	17%	**16**
CA-58	0%	17%	44%	21%	18%	**18**
CH-22	20%	20%	35%	14%	11%	**17.5**
CL-47	50%	8%	36%	0%	6%	**15.5**
CN-17N	0%	0%	43%	0%	57%	**17**
CZ-80	0%	9%	64%	4%	23%	**18**
DE-31S	0%	0%	71%	10%	19%	**18**
DE-90N	0%	2%	70%	5%	23%	**18.5**
DK-125	0%	0%	68%	13%	19%	**18**
ES-50NW	6%	20%	29%	0%	45%	**22.5**
FI-25	0%	0%	56%	32%	12%	**15.5**
FR-50-W	13%	14%	52%	0%	21%	**20.1**
ID-3NG	49%	0%	0%	0%	51%	**12.5**
IE-48	27%	27%	26%	0%	20%	**16**
IN-3E	0%	0%	66%	10%	24%	**9.5**
IN-3S	28%	0%	34%	0%	38%	**13**
IT-154	0%	0%	70%	9%	21%	**23**
LowEuro-5 (*)	30%	30%	20%	10%	10%	**12**
LowTropical-10 (*)	80%	0%	0%	0%	20%	**8**
MX-20	0%	8%	54%	0%	38%	**12.5**
NL-70	0%	21%	52%	1%	26%	**19**
NZ-351	83%	0%	17%	0%	0%	**14.3**
PE-7	42%	42%	0%	0%	16%	**8.5**
PL-15	9%	20%	66%	5%	0%	**18**
PY-45	0%	0%	58%	0%	42%	**16**
RU-900	0%	0%	59%	31%	10%	**16.5**
SE-60	0%	4%	58%	0%	38%	**20**
UK-149NW	10%	23%	41%	4%	22%	**22**
US-2218NY	0%	0%	49%	4%	47%	**25.6**
US-80WI	0%	0%	63%	30%	7%	**24**

(*) Archetypes created in addition to those of the global study (FAO, IDF, IFCN 2014).

4.3 Feed for dairy cows

4.3.1 General feed

Supporting animals (dry cows and heifers) are fed with a less rich feed intake (less or no compound feed). In general, the supporting animals' emissions of enteric methane (altogether) amount to about half of the emissions from lactating cows.

The feed baskets are modelled according to FAO, IDF, IFCN (2014). WFLDB and ecoinvent 3.5 datasets are used to model input feed and grass fodder (grazed grass, hay, grass silage), according to the general framework

described in section **Error! Reference source not found.**. These include land use change when relevant (e.g. soybean production).

Protein concentrates were created specifically for dairy cows and are described in the following section.

4.3.2 Protein concentrate feed production

The protein concentrate feed is differentiated according to 4 main supply areas: North America (RNA), South America (RSA), Europe (RER) and rest of the World (RoW). The archetypes that are used in countries in more than one supply area (for instance, the New Zealander archetype NZ-351 is used in New Zealand and in Ireland) exist in versions covering all the possible supply areas (in this example: RoW and RER).

The ingredients of the protein feed concentrate are detailed in Tab. 44. Energy, infrastructure, water used for the processing as well as delivery transports are also included. The origin of the ingredients as well as the electricity mix are adapted to the geography. 3 geographies are covered: Europe, Latin America and North America.

Tab. 44: Ingredients for the protein concentrate feed

Product	Mass proportion (kg/kg)
Rapeseed	0.22
Soybean feed	0.5
Lime	0.022
Magnesium oxide	0.004
Maize starch	0.2
Molasses	0.05
Sodium chlorate	0.004

This process uses the soybean input reflecting the European import mix as described by Rabobank (2017).

4.4 National mix for raw milk and regional averages

Archetypes are combined as to represent the typical mix of dairy systems in different countries. These mixes as based on qualitative information retrieved from IDF and IFCN (FAO, IDF, IFCN 2014). Most were crosschecked by experts and with existing datasets from other LCI databases (e.g. AGRIBALYSE).

Tab. 45: National mixes for milk production based on WFLDB dairy farm archetypes

IFCN typical farm	AT	AU	BE	BR	CA	CH	CL	CN	CO	CZ	DE	DK	ES	FI	FR	GB	GR	HU
AT-14	50%					30%				10%	10%		10%		25%			
AU-275WA		60%																
BE-45			40%										10%		25%	10%		
BR-20S				28%					5%									
CA-58					40%													
CH-22						50%									10%			
CL-47							26%		5%									
CN-17N								58%										
CZ-80										50%								10%
DE-31S	40%		30%			10%				10%	20%						50%	
DE-90N											50%							
DK-125											20%	88%		25%	5%			
ES-50NW													60%					
FI-25														50%				
FR-50-W	10%					10%									35%			10%
ID-3NG																		
IE-48																		

IN-3E																	
IN-3S																	
IT-154																30%	
LowEuro-5																	
LowTropical-10				72%			54%	42%	85%								
MX-20												10%				20%	
NL-70											12%	10%	25%		30%		
NZ-351																	
PE-7							20%		5%								
PL-15																	50%
PY-45		40%															
RU-900																	
SE-60																	
UK-149NW			30%		15%					30%					60%		30%
US-2218NY																	
US-80WI					45%												

National mixes for milk production based on WFLDB dairy farm archetypes (continued)

IFCN typical farm	**ID**	**IE**	**IN**	**IT**	**MX**	**NL**	**NZ**	**PK**	**PL**	**PT**	**PT**	**PY**	**RO**	**RU**	**SE**	**SK**	**US**
AT-14		5%		30%					30%						5%		
AU-275WA																	
BE-45						13%											
BR-20S																	
CA-58																	
CH-22																	
CL-47					10%												
CN-17N																	
CZ-80													7%			10%	
DE-31S				15%											16%		
DE-90N																	
DK-125						10%									50%		
ES-50NW										40%	40%						
FI-25						6%											
FR-50-W										10%	10%						
ID-3NG	50%																
IE-48		40%															
IN-3E			50%					30%									
IN-3S			20%														
IT-154				30%													
LowEuro-5		5%							30%	10%	10%		75%	40%		20%	
LowTropical-10	50%		30%		15%							45%					
MX-20					65%			70%		10%	10%						
NL-70						47%											

| | | |

5 Food processing

5.1 Oil extraction

Existing processes available in ecoinvent are used to model oil extraction. The process 'Rape oil, at oil mill/RER U' is used for linseed and rapeseed oil, 'Soybean oil, at oil mill/US U' is used as a proxy for olive oil, peanut oil, soybean oil and maize oil. 'Crude coconut oil, at plant/PH U' is used as for coconut oil. 'Palm oil, at oil mill/MY U' is used as for palm oil and palm kernel oil. The oil yield (i.e. yield of crop needed to produce 1 kg oil) is adapted to each crop (Tab. 46).

Tab. 46: Amount of raw product need to produce 1 kg of oil

Crop	kg FM/ kg oil	Source
Peanut, with shell	2.7	Boriss & Kreith, Agricultural Issues Center, University of California. Available at: http://www.agmrc.org/commodities__products/nuts/peanut-profile/# (13.10.2014)
Sunflower, seed with hull	3.3	www.feedipedia.com
Coconut, dehusked	2.97	ecoinvent 2.2
Linseed, seed	3.3	Gutiérrez et al.; J. Soil Sci. Plant Nutr. 10 (4): 454 - 463 (2010)
Palm oil and palm kernel oil	4.5	Schmidt et al. 2020
Olive	5	http://ec.europa.eu/agriculture/olive-oil/economic-analysis_en.pdf
Maize, germ	2.56	Corn Refiners Association. Corn oil. 5th ed, 2006; Available at: http://www.corn.org/wp-content/uploads/2009/12/CornOil.pdf
Rapeseed, seed	2.15	Source 83 (external documentation)
Soybean, with hull	5.8	Bailey's Industrial Oil and fat Products, Sixth Edition 2005. Chapter 13 - Soybean Oil, 577-653. https://pharosproject.net/uploads/files/cml/1360080729.pdf

Oil extraction datasets are modelled as multi-output processes generating several co-products. Economic allocation is applied for oil production at oil mill for which details are given in Tab. 47.

Tab. 47: Economic allocation between oil and oil cake

Oil production			Amounts			Economic allocation	
Product (oil)	Price ratio cake/oil (kg/ kg)*	Source	Oil (kg)	Grains/oil (kg*/kg)	Amount of oil cake (kg*)	Price oil in %	Price cake in %
Linseed oil	0.18	0151	1.0	3.3	2.3	70%	30%
Olive oil	0.14	0154	1.0	5.0	4.0	64%	36%
Peanut oil	0.10	0152	1.0	2.7	1.7	86%	14%
Rapeseed oil	0.29	0153	1.0	2.2	1.2	75%	25%
Soybean oil	0.39	0150	1.0	5.8	3.72	see Tab. 48 below	see Tab. 48 below
Sunflower oil	0.15	0151	1.0	3.3	2.3	see Tab. 48 below	see Tab. 48 below
Maize oil	0.23	0151	1.0	2.56	1.56	74%	26%
	* fresh matter						
Coconut oil	0.15	5017	1.0	2.97 (dehusked)	1.62	82%	18%

For soybean and sunflower, more co-products are generated during the crushing process and are summarized in Tab. 48.

Tab. 48: Economic allocation for soybean and sunflower co-products

	Amount	Price (EUR/kg)	Source	Economic allocation
Soybean oil	1	0.759	Schneider and Finkbeiner (2013)	39.7%
Soybean oil cake	3.72	0.297	Schneider and Finkbeiner (2013)	57.6%
Soybean hulls	0.39	0.101	Ratio of hull to meal price taken as 0.34 from USDA report (2022)	2.1%
Soybean lecithin	0.02	0.600	Schneider and Finkbeiner (2013)	0.6%
Sunflower oil	1	1.44	-	73.8%
Sunflower oil cake	2.3	0.22	-	25.9%
Sunflower lecithin	0.01	0.6	0.3% on a seed basis Nieuwenhuyzen (2014) Price assumed the same as soybean lecithin	0.30%

5.1.1 Palm oil processing

The palm fruit bunch oil extraction (crude palm oil datasets) produces the following co-products: crude palm oil, crude palm kernel oil and palm kernel meal. These palm oil processing datasets are based on the publication by Schmidt et al. 2015 and Schmidt et al. 2020.

The reference flow is 1 metric tonne of palm fresh fruit bunches (FFB) that deliver the following co-products:

- RSPO: 219 kg of crude palm oil, 25.1 kg of crude palm kernel oil and 29.1 kg of palm kernel meal.
- Non-RSPO: 198 kg of crude palm oil, 24.2 kg of crude palm kernel oil and 28.1 kg of palm kernel meal.

An economic allocation has been applied based on ecoinvent 3.9.1 and because the share of the different co-products are slightly different for RSPO and non-RSPO, the final allocation key varies:

- *RSPO:* 82.4% for crude palm oil, 16.3% for crude palm kernel oil, 1.3% of palm kernel meal
- *non-RSPO:* 81.4% for crude palm oil, 17.2% for crude palm kernel oil, 1.4% of palm kernel meal

The technology applied in those datasets is a typical palm oil mill designed for palm oil and palm kernel oil extraction in an Indonesian or Malaysian context. Palm fruit bunches undergo sterilization, stripping, digestion, oil extraction, screening and settling. The inventory covers the following steps too: energy supply from extracted solids (fibres, shells, digester solids and empty fruit bunches), biogas generation from Palm Oil Mill Effluent (POME) and treatment of specific wastewater effluents.

The POME is treated either by an anaerobic pond or in a biogas generation system. According to Schmidt 2020, 16% of the POME is treated in a biogas generation system for RSPO and 2.4% for non-RSPO.

Methane, dinitrogen monoxide and ammonia emissions to air from POME treatment by anaerobic pond are calculated and calibrated to match methane emissions reported by Schmidt 2020. To these, the water emissions from POME treatment were considered, with the assumption that 50% is emitted to air and 50% to surface water. When POME is treated in a biogas generation system, the methane emissions are based on Schmidt 2020; and 10% of the dinitrogen monoxide and ammonia emissions as calculated from the treatment with the anaerobic pond are considered, corresponding to the fugitive emissions.

Data sources:

- Schmidt J, 2015. Life cycle assessment of five vegetable oils. Journal of Cleaner Production, Volume 87.
- Schmidt J, De Rosa M, 2020. Certified palm oil reduces greenhouse gas emissions compared to non-certified. Journal of Cleaner Production, Volume 277.

5.2 Oil fractioning

5.2.1 Palm oil fractions

The dataset has been created based on primary data from the publication Yew Ai Tan et al. (2010).

The reference flow is 1 kg of refined palm oil fractioned in 0.75 kg palm oil olein (Palm oil olein, at plant (WFLDB)/GLO U) and 0.25 kg palm oil stearin (Palm oil stearin, at plant (WFLDB)/GLO U).

An economic allocation has been applied based on Yew Ai Tan (2010)

- 77% for palm olein
- 23% for palm stearin

Fractionation is the crystallization of refined palm olein (RPO) under controlled conditions followed by separation of the low melting liquid phase (olein) and the high melting solid phase (stearin). This process involves cooling RPO in crystallizers to partition the liquid olein from the solid stearin, followed by separation of the olein from the stearin by passing the mixture through a high pressure membrane press. As most fractionation plants are located in the same premises as refineries, both facilities share energy and water input, and data for their respective allocations to refineries and fractionation plants are provided by a survey questionnaire as well as through on-site verification visits to refineries.

Data sources:

- Yew Ai Tan et al. (2010) Life cycle assessment of refined palm oil production and fractionation (part 4) Journal of Oil Palm Research Vol. 22

5.2.2 Coconut oil fractions

The dataset has been created based on primary data from the publication from Gervajio (2005).

The reference flow is 1000 kg of coconut oil providing 935 kg of different fatty acids. For a 1000 kg triglycerine feed, we estimate that 935 kg of fatty acids are produced (molar mass of triglycerine with in average 12 C: 600 g / mol and molar mass of fatty acid with in average 12 C: 561 g/mol).

The different co-products are:

- Caprylic-capric acid (C8-C10) from coconut oil fractionation, at plant (WFLDB)/GLO U
- Topped coconut fatty acid (C12-C18) from coconut oil fractionation, at plant (WFLDB)/GLO U
- Lauric acid (C12-C14) from coconut oil fractionation, at plant (WFLDB)/GLO U
- Myristic acid (C12-C14) from coconut oil fractionation, at plant (WFLDB)/GLO U
- Sweetwater from coconut oil fractionation, at plant (WFLDB)/GLO U

A mass allocation is used as a proxy for economic allocation given the high uncertainty on different fatty acids economic values. Sweetwater is a by-product of the fat splitting process. It is considered as a by-product with no economic value (Ooi 2004). It contains glycerine which can be extracted and valorized.

Coconut oil is hydrolysed and split into fatty acids and glycerine. The continuous process (high pressure fat-splitting process, known as Colgate Emery process) is the most efficient of the current methods of fat hydrolysis. Full countercurrent flow of oil and water produces a high degree of splitting without the need of a catalyst. Fatty acids are then purified and separated into fractions by distillation and fractionation. The energy used for fractionation is excluded because of lack of data. The inputs are based on a publication from Gervajio (2005).

Data sources:

- Gervajio G C (2005). Fatty acids and derivatives from coconut oil, Bailey's Industrial Oil and Fat Products, F. Shahidi Editions, Part 6 Industrial and nonedible products from oils and fats.

- Ooi T L, Yong K C, Hazimah A H, Dzulkefly K, Yunus W M Z (2004). Glycerol residue – a rich source of glycerol and medium chain fatty acids. Jounral of Olea Science, Vol 53 (1), 29-33.

5.3 Dehydration

This section describes the processes used in the WFLDB for water removal from food products:

- Dehydration in hot air tunnel
- Evaporation in a thermal vapor recompression (TVR) evaporator
- Dehydration by spray drying (generic version and coffee specific version)
- Dehydration by freeze drying (coffee specific version only)

It describes the main data sources, assumptions, how to use the datasets and for what they are suitable.

5.3.1 Dehydration in hot air tunnel

Hot air tunnel is the most common dehydration process used in the food industry. As it is not very efficient, it is being replaced by better technologies. However, in 2018, there is still a low replacement rate and this technique is considered to be representative for the next decade. This dataset is based on literature and corresponds to a process with heat made from natural gas circulated in a container. It includes energy inputs based on estimated efficiency and approximated infrastructure.

Data sources:

- Tippayawong N, Tantakitti C, Thavornun S (2008) Energy efficiency improvements in longan drying practice. Energy 33:1137–1143. doi: 10.1016/j.energy.2008.02.007
- Beigi M (2016) Energy efficiency and moisture diffusivity of apple slices during convective drying. Food Sci Technol 36:145–150. doi: 10.1590/1678-457X.0068

Assumptions:

- Vapor is extracted at a temperature of 150°C.
- Process efficiency is around 30%.

Dataset recommended use:

This dataset typically applies to fruit drying and similar products. To be used per kg of removed water, for any range of moisture (i.e. applies from 99% moisture content to 5% moisture content).

5.3.2 Evaporation in a thermal vapor recompression (TVR) evaporator

This dataset is based on literature from milk processing equipment manufacturer and should be used when evaluating evaporation of water from raw (or skimmed) milk to produce evaporated milk. Basic solid contents are 9-13% for input and 50% for output.

Data sources:

- Collected data from a European company whose equipment is used worldwide, 2011.
- GEA Process Engineering (2010)

Assumptions:

The dataset includes the energy demand (supplied by consumption of electricity) and steam production (from natural gas) for evaporating 1 kg of water. It does not include waste and emissions to environment (except water from steam to air).

Dataset recommended use:

This dataset typically applies to milk drying or similar liquids. To be used per kg of removed water, for a typical range of moisture from 5% - 15% dry matter to 50% - 70% dry matter. Cannot be used for complete drying.

5.3.3 Dehydration by spray drying – generic

This dataset is based on literature from milk processing equipment manufacturer and should be used when evaluating evaporation of water from evaporated milk to produce milk powder. Basic solid contents are 50% for evaporated milk at input and 96.5% for milk powder at output. The processing consists in two-stage drying in a spray dryer operated at high temperature (200° C) with Vibro-Fluidizer. The spray dryer and fluid bed power consumption are respectively 130 kW and 20 kW. Fuel oil consumption of the spray dryer is 205 kg/h and steam consumption of the fluid bed is 167 kg/h. Evaporator capacity is 3.5 tonnes of evaporated milk per hour.

Data sources:

- Collected data from a European company whose equipment is used worldwide, 2011.
- GEA Process Engineering (2010)

Assumptions:

The dataset includes the energy demand (supplied by consumption of electricity and oil) and steam production (from natural gas) for evaporating 1 kg of water. It does not include waste and emissions to environment (except water from steam to air). Steam production from natural gas is assumed.

Dataset recommended use:

This dataset typically applies to milk drying or similar liquids. To be used par kg or removed water, for a typical range of moisture from 50% dry matter to 97% dry matter.

For soluble coffee, there is a specific dataset for the transformation of green coffee into spray dried soluble coffee (see below).

5.3.4 Dehydration by spray drying – soluble coffee specific

This process (Transformation into spray-dried soluble coffee, green coffee, per kg product (WFLDB)/GLO U) covers the production of spray-dried soluble coffee from green coffee, including roasting, extraction, concentration, spray drying, agglomeration and conditioning. The inventory includes the inputs of energy, water, the factory building and the direct emissions related to roasting and to the coffee grounds burning.

The green coffee input and its transport to the factory are excluded, as well as the packaging of the finished product. 2.22 kg green coffee beans are needed to produce 1 kg spray dried coffee.

Data sources:

- Collected data, as published by Humbert et al. (2009).

Dataset recommended use:

This dataset only applies to soluble spray dried coffee. To be used par kg of soluble coffee, without initial evaporation or concentration.

5.3.5 Dehydration by freeze drying – soluble coffee specific

This process (Transformation into freeze-dried soluble coffee, green coffee, per kg product (WFLDB)/GLO U) covers the production of freeze-dried soluble coffee from green coffee, including roasting, extraction, concentration, freeze drying, agglomeration and conditioning. The inventory includes the inputs of energy, water, the factory building and the direct emissions related to roasting and to the coffee grounds burning.

The green coffee input and its transport to the factory are excluded, as well as the packaging of the finished product. 2.60 kg green coffee beans are needed to produce 1 kg freeze dried coffee.

Data sources:

- Collected data from a European company whose equipment is used worldwide, 2011.

Dataset recommended use:

This dataset only applies to soluble freeze dried coffee. To be used per kg of soluble coffee, without initial evaporation or concentration.

5.4 Cocoa processing and chocolate manufacturing

Cocoa transformation is modelled as a multi-output process generating four co-products. Economic allocation is applied with the factors presented in Tab. 49.

Tab. 49: Allocation factor for cocoa co-products

	t product from 1 t of cocoa beans, sun-dried input [1]	Average price (USD/t)	Allocation factor
Cocoa liquor	0.32	3250 [2]	38.1%
Cocoa butter	0.23	3250 [3]	27.6%
Cocoa powder	0.29	3250 [3]	34.1%
Cocoa shells	0.10	60 [2]	0.2%

[1] Based on Ntiamoah and Afrane 2008
[2] Data from Barry Callebaut and Mars experts
[3] Prices taken on www.alibaba.com

Cocoa co-products are modelled for the following geographical areas and supplying countries (all data based on Barry Callebaut expertise):

Tab. 50: Processing countries and origin of cocoa beans

		Countries where beans are processed into cocoa products							
		Ivory Coast	Ghana	Cameroon	Europe	North America	Indonesia	Malaysia	Brazil
Countries of origin	Ivory coast	100%			49%	61%	15%	22%	
	Ghana		100%		17%	16%	2%	33%	20%
	Ecuador				3%	15%	2%	3%	
	Indonesia						75%	13%	
	Cameroon			100%	8%		2%	8%	
	Nigeria				9%	0%		3%	
	Brasil								80%
	others				14%	8%	4%	18%	
	Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

The delivery of cocoa beans from producing countries to manufacturing place is based on assumptions and on www.searates.com for the transoceanic freight ship distances. The processing of dried cocoa beans into the five co-product is based on data from Ntiamoah and Afrane 2008 for the co-products amounts and water and data from WFLDB partners for the energy consumption (gas and electricity).

Chocolate is manufactured with cocoa liquor, cocoa butter, sugar, milk powder (except for dark chocolate) and soy lecithin. The European "RER" cocoa products are used as inputs for chocolate. 10% loss rate of main ingredients is assumed in the process (expert estimate). Three chocolate datasets are included in WFLDB:

- Dark chocolate (51% cocoa)

- Milk chocolate
- White chocolate

Energy use for chocolate manufacturing is based on data collected from WFLDB partners. The packaging is excluded from the modelling.

Data sources:

- Ntiamoah and Afrane 2008: Ntiamoah A, Afrane G, 2008. Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach. Journal of Cleaner Production 16, 1735-1740.
- WFLDB industrial partners expertise

5.5 Coffee cherries processing

For the latest developed geographies, the processing of coffee cherries into green coffee beans is separated from the crop cultivation at farm.

The processing can sometimes happen at farm, sometimes in cooperatives.

The following datasets were developed:

- Washed arabica coffee in Guatemala
- Washed arabica coffee in Mexico
- Unwashed robusta coffee in Vietnam

5.5.1 Washed arabica coffee in Guatemala and Mexico

In Guatemala and Mexico, most of the arabica coffee cherries are treated with the wet process according to coffee experts contacted by Peterson Control Union in these two countries. The Guatemalan and the Mexican washed arabica coffee are based on the same data, regionalising the electricity mix and water flows to fit to the two locations. The product obtained is green coffee beans with a moisture content of 10%.

The process includes the input of coffee cherries, the transport of harvested coffee cherries to processing place, the washing, depulping, fermentation and drying of coffee. The infrastructure is not included in the inventory.

The input of coffee cherries is based on Wintgens 2004, i.e., 5.5 t coffee cherries for 1 t of dry green coffee output. The transport from farm to factory is assumed to be done by small trucks (3.5-7.5 t) and on a distance of 50 km. The electricity consumption is calculated considering the use of different machines based on Escobar 2013, including: reception and classification (2.17 kWh/t coffee cherries, “Oscar 1/Oscar 2” siphon machines), depulping (2.6 kWh/t coffee cherries, “compacto 1D/2D/3D” depulping machine) and drying (3.27 kWh/t coffee cherries, “secadora rotative ser 150x” drying machine). The water input of 19 L/kg dry parchment is based on Oliva Pichiya 2012 and considering 0.806 kg of green coffee/kg dry parchment according to Wintgens 2004. This water is assumed to be entirely emitted to river, with a COD and P content of the effluent based on Oliva-Pichiya 2012 (1664 mg COD/L and 9.7 mg P/L).

Tab. 51: Arabica coffee cherries wet process in Guatemala and Mexico

	Amount / kg green coffee	Unit	Reference
Coffee cherries	5.5	kg	Wintgens 2004
Transport by truck	0.275	tkm	Assumption, Wintgens 2004
Electricity	0.044	kWh	Escobar 2013, Wintgens 2004
Water from unspecified natural origin	23.5	kg	Oliva Pichiya 2012, Wintgens 2004
Water, to river	23.6	kg	Assumption
COD, to river	0.039	kg	Oliva-Pichiya 2012
Phosphorus, to river	0.00023	kg	Oliva-Pichiya 2012

Data sources:

- Escobar R, Arestegui M, Moreno A, Sanchez L, 2013. Catalogo de maquinaria para procesamiento de café. Cooperacion Alemana al Desarrollo GIZ in Peru. Retrieved on https://energypedia.info/images/d/d1/Maquinaria_para_Caf%C3%A9.pdf, June 2023.
- Oliva Pichiyá WA, 2012. Aporte al desarrollo de la caficultura de pequeños productores mediante la caracterización de los beneficios húmedos de café de la cooperativa Hoja Blanca y análisis del vertido de aguas mieles en la microcuenca del río Hoja Blanca, Cuilco, Huehuetenango, Guatemala, C.A. Graduation work, University of San Carlos de Guatemala. Retrieved on https://core.ac.uk/download/pdf/94668647.pdf, June 2023.
- Wintgens, JN, 2004. Coffee: Growing, Processing, Sustainable Production. A guide for growers, traders, and researchers. WILEY-VCH Verlag GmbH and Co.KGaA, Weinheim, Germany.

5.5.2 Unwashed robusta coffee in Vietnam

In Vietnam, most of the robusta coffee cherries are treated with the dry process according to Peterson Control Union experts. The product obtained is green coffee beans with a moisture content of 10%.

The process includes the input of coffee cherries, the transport of harvested coffee cherries to processing place, the drying and milling of coffee. The infrastructure is not included in the inventory.

The input of coffee cherries is based on Wintgens 2004, i.e., 5.5 t coffee cherries for 1 t of dry green coffee output. The transport from farm to factory is modelled considering the petrol consumption for the small trucks used according to Trinh et al 2019 (0.0011 L gasoline/kg green coffee) and adapting it to MJ considering the default ecoinvent conversion factors (0.75 kg/L and 42.5 MJ/kg). The energy consumption for processing is diesel and based on Trinh et al 2019: 0.005 L diesel/kg green coffee and adapting it to MJ considering the default ecoinvent conversion factors (0.84 kg/L and 42.8 MJ/kg). Lubricant is also considering according to Trinh et al 2019, with 0.0009 L/kg green coffee (adapted considering a density of 0.88 kg/L according to https://www.cbs.nl/en-gb/our-services/methods/definitions/weight-units-energy#:~:text=%2D%20Lubricants%3A%201%20litre%20%3D%200.88%20kilogram). The water input of 0.015 L/kg green coffee is based on Trinh et al 2019 and the process water input is assumed to be fully discarded to river, without emissions of COD and phosphorus to river as water is not used for depulping but for some cleaning and therefore considered as not charged as much as for wet process.

Tab. 52: Robusta coffee cherries dry process in Vietnam

	Amount / kg green coffee	Unit	Reference
Coffee cherries	5.5	kg	Wintgens 2004
Gasoline	0.035	MJ	Trinh et al 2019
Diesel	0.18	MJ	Trinh et al 2019
Lubricating oil	0.0008	Kg	Trinh et al 2019, https://www.cbs.nl/en-gb/our-services/methods/definitions/weight-units-energy#:~:text=%2D%20Lubricants%3A%201%20litre%20%3D%200.88%20kilogram
Water from unspecified natural origin	0.015	kg	Trinh et al 2019
Water, to river	0.015	kg	Assumption

Data sources:

- Trinh LTK, Hu AH, Lan YC, Chen ZH, 2019. Comparative life cycle assessment for conventional and organic coffee cultivation in Vietnam. International Journal of Environmental Science and Technology, 17.
- Wintgens, JN, 2004. Coffee: Growing, Processing, Sustainable Production. A guide for growers, traders, and researchers. WILEY-VCH Verlag GmbH and Co.KGaA, Weinheim, Germany.

- https://www.cbs.nl/en-gb/our-services/methods/definitions/weight-units-energy#:~:text=%2D%20Lubricants%3A%201%20litre%20%3D%200.88%20kilogram

5.6 Coffee transformation

Coffee transformation is modelled based on literature, public references, expert knowledge and corporate data from various coffee manufacturers.

The following processing stages are included:

- Ground burning
- Roasting and grinding
- Decaffeination (supercritical CO_2 process)
- Spray drying (see section 5.3 for more info)
- Freeze drying (see section 5.3 for more info)

The ratios below are considered (based on Humbert 2009):

- 1.23 kg green coffee beans per kg roasted and ground coffee
- 2.22 kg green coffee beans per kg spray dried coffee
- 2.60 kg green coffee beans per kg freeze dried coffee

The following coffee products are included in WFLDB:

- Coffee, decaffeinated (CO_2), freeze dried, at plant (WFLDB)/GLO U
- Coffee, decaffeinated (CO_2), roast and ground, at plant (WFLDB)/GLO U
- Coffee, decaffeinated (CO_2), spray dried, at plant (WFLDB)/GLO U
- Coffee, regular, freeze dried, at plant (WFLDB)/GLO U
- Coffee, regular, roast and ground, at plant (WFLDB)/GLO U

Data sources:

- Humbert S, Loerincik Y, Rossi V, Margni M, Jolliet O (2009). Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso), Journal of Cleaner Production, Vol 17 (15), 1351-1358.
- Frels C (1990). A contribution to the measurement and evaluation of gaseous organic emissions in coffee roasting plants with downstream catalytic combustors. Thesis in organic chemistry. Hamburg University.

5.7 Tomato processing

Tomato processing is modelled based on literature data and specific machinery data. Three processed tomato products are provided in WFLDB, as per Tab. 53.

Tab. 53: Inputs to processed tomato products

Inputs	Tomato pulp 5° Brix	Tomato juice 12° Brix	Tomato paste 30° Brix
Tomato, processing grade (kg/kg)	1.03	0.742	6.18
Tomato paste (kg/kg)	-	0.28	-
Electricity (kWh/kg)	0.00208	0.00754	0.0715
Steam (kg/kg)	-	-	3.12
Water (L/kg)	4.12	2.97	169

Data sources:

- Fenco Food Machinery (2012). Technical data from company website: www.fenco.it. Retrieved in May 2012
- Karakaya A, Özilgen M (2011) Energy utilization and carbon dioxide emission in the fresh, paste, whole-peeled, diced, and juiced tomato production processes. Energy 36 (2011) 5101-5110
- Shanghai Jiadi Machinery (2012) A tomato paste processing line - from fresh tomato until 5-220L aseptic filling. Technical catalogue. Shanghai Jiadi Machinery Co. Ltd. www.tomatomachinery.com. Retrieved in May 2012

5.8 Bread and pasta manufacturing

Modelling of bread and dried pasta is based on literature data. The first step for bread and pasta manufacturing is the production of wheat flour, wheat feed flour, wheat bran and wheat middlings (Tab. 54) and semolina (

Tab. 55). Wheat flour co-products are based on economic data generated within the ACYVIA project. ACYVIA was a LCA database development project on food transformation founded by ADEME realized together with French agro-food technical centers, as well as Quantis and Agroscope. As part of this project, datasets for wheat flour have been developed. An economic allocation is recommended for wheat co-product allocation.

Tab. 54: Allocation factors for wheat flour, feed flour, bran and middlings based on ACYVIA data

Products	Quantity kg for 1 t wheat	Economic value in EUR/t based on a literature review	Allocation factor
Wheat flour	781	0.3	90%
Wheat feed flour	50	0.104 (same as middlings)	2%
Wheat bran	120	0.151	7%
Wheat middlings	35	0.104	1%

Tab. 55: Co-products allocation from semolina production

Semolina for pasta	
Co-products	**Allocation**
Durum wheat semolina	89%
Durum wheat bran	11%

For wheat flour, the global average for wheat grain is used as input. For durum wheat semolina, durum wheat is used as input.

For bread and pasta, the ingredients as well as the processing energy are included. Packaging is not included.

Data sources:

- Zygouras G, Kornaros M, Angelopoulos K (2005) Life Cycle Assessment (LCA) as a tool for assessing the environmental performance of flour production in Greece. Proceedings of the 9th International Conference on Environmental Science and Technology, Rhodes Island, Greece
- Andersson, K., & Ohlsson, T. (1999). Life Cycle Assessment of Bread Produced on Different Scales. International Journal of LCA 1, 25-40
- Bimpeh, M., Djokoto, E., Doe, H., & Jequier, R. (2006). Life Cycle Assessment (LCA) of the Production of Home made and Industrial Bread in Sweden. KTH, Stockholm.
- Espinoza-Orias, N., Stichnothe, H., & Azapagic, A. (2011). The carbon footprint of bread. International journal of LCA , 16, 351-365
- Bevilaqua M, Braglia M, Carmignani G, Zammori F A (2007) Life cycle assessment of pasta production in Italy. Journal of food quality, vol 30, pp 932-952.
- **literature review performed for the ACYVIA project**
- FranceAgriMer - Observatoire des prix et des marges
- CLAL - Prices of livestock foods: cereals and by-products
- AgEBB - University of Missouri

5.9 Dairy products manufacturing

Modelling of dairy products is based on literature data, on the European draft Product Environmental Category Rules (PEFCR) for Dairy products (EDA 2015, EDA 2018) and on expert inputs. The following dairy products are included in WFLDB:

- Liquid milk (whole, semi-skimmed and skimmed)
- Cream
- Butter (salted and unsalted)
- Buttermilk
- Butter oil
- Soft cheese, Camembert-style
- Hard cheese, Emmental-style
- Whey (liquid)
- Thick whey
- Milk concentrate (25% and 50%)
- Milk powder (whole and skimmed)
- Buttermilk powder
- Whey powder
- Yogurt

Dairy products manufacturing is typically a multi-product activity. Allocation between co-products is done base on their dry matter content (IDF 2015). The RER and RNA averages for raw milk at the farm are used as input to the different dairy products. Packaging is not included.

Data sources:

- Actalia (2014) LCA modelling of typical hard and soft cheese. Data from several French producers.
- EDA (2015) Product Environmental Footprint Category Rules for Dairy Products. Draft version, June 2015. European Dairy Federation. Brussels, Belgium
- EDA (2018) Product Environmental Footprint Category Rules for Dairy Products. Version 1.0, April 2018. European Dairy Federation. Brussels, Belgium

5.10 Margarine production

Three different types of margarine products are included in WFLDB, based on literature data:

- Margarine, 38% fat, typical of British production and consumption
- Margarine, 60% fat, typical of Spain production and consumption on the French market
- Margarine, 70% fat, typical of German production and consumption on the German and Dutch markets

Packaging is not included.

Data source:

- Nillson K., Flysjö A., Davis J., Sim S., Bell S. (2010) Comparative life cycle assessment of margarine and butter consumed in the UK, Germany and France. Int J Life Cycle Assess (2010) 15:916–926 DOI 10.1007/s11367-010-0220-3

5.11 Sugar production

For sugar from sugar beet, the ecoinvent (3.4) dataset was used and input products (sugar beet and ammonia) are modified to include WFLDB data instead of ecoinvent.

For sugar from sugarcane, the ecoinvent (3.9.1) datasets (traditional annexed plant and modern annexed plant) are adapted to consider the unallocated multi-output dataset and the sugarcane inputs were modified into WFLDB datasets. They correspond to raw sugar. For Brazil, the traditional annexed plant and modern annexed plant datasets are built while for the other geographies, only the traditional annexed plant is modelled. This is based on the global sugar from sugarcane that has the two types of plants for Brazil but only traditional annexed plant for rest of the world.

For sugar from sugar beet and from sugarcane, packaging is not included.

5.12 Mineral water

Modelling of mineral water is based on literature data and on the European draft Product Environmental Category Rules (PEFCR) for Packed Water (EFBW 2015). The following products are included in WFLDB:

- Mineral water, sparkling, glass refillable, 1.0 L
- Mineral water, still, glass refillable, 1.0 L
- Mineral water, still, PET one-way, 0.5 L
- Mineral water, still, PET one-way, 1.5 L

Packaging is included.

Data sources:

- Dettore, C. G. (2009) Comparative Life-Cycle Assessment of Bottled vs. Tap Water Systems. Water, 110.
- EFBW (2015) Product Environmental Footprint Category Rules for Packed Water. Draft version, June 2015. European Federation of Bottled Waters. Brussels, Belgium

5.13 Maize dry and wet milling

Modelling of co-products from dry and wet milling of maize grain is based on the sectional draft Product Environmental Category Rules for Feed (FEFAC 2015). The dry milling process results in the following co-products: maize flour and maize middlings. The wet milling process results in the following co-products: wet maize starch, maize gluten, maize bran and maize steepwater solubles. Economic allocation is applied as per FEFAC (2015). Wet maize starch shall be dried before its use in other industrial applications. The drying operation has been calculated based on (Galitsky 2003).

5.14 Raw and processed honey

Modelling of raw and processed honey was developed for small-scale (Switzerland) and large-scale (United States) honey productions based on primary (personal communication) and literature data. Raw honey includes cradle-to-farm processes (i.e. wood for the bee hive infrastructure, inputs for bee feeding and pest management, commuting of the beekeeper to the bee hives, etc.) and finishes with the production of an un-treated and heterogeneous honey directly collected at farm. Processed honey includes raw honey production, all farm-to-gate processes (i.e. transport from honey producer to honey processor, electricity and heat requirements for raw honey processing, etc) and finishes with the production of a treated and homogeneous honey.

Honey being packaged in a large variety of packaging materials and sizes, both raw and processed honey datasets do not include packaging.

Finally, although beewax, nucs, pollen and fruit tree pollination are all co-products from honey production, the entire beekeeping activity is allocated to the raw honey production.

Data sources:

- Kendall, A., Yuan, J. & Brodt, S.B.,Carbon footprint and air emissions inventories for US honey production: case studies, Int J Life Cycle Assess (2013) 18: 392. https://doi.org/10.1007/s11367-012-0487-7
- Kendall, A. Yuan, J. Brodt, S. Kramer, K.J., Carbon Footprint of U.S. Honey Production and Packing, University of California (UC) Davis (2011)

5.15 Guar gum

The process "Guar gum splits, at plant" is a multi-output process where guar seeds are transformed into guar gum splits, germ and hull. The dataset created is based on literature data, adapted from data provided by Sunil Kumar, Simapro India.

1'000 kg of guar seed provide 310 kg of guar gum, 400 kg of guar seed germ and 290 kg of guar seed hull. Tab. 56 shows the economic value as well as the derived allocation factors.

Tab. 56: Economic values and allocation factor used for guar seed processing products

Product	Economic value	Allocation factor
Guar gum splits	0.27 $/kg	70%
Guar seed germ	0.055 $/kg	18%
Guar seed hull	0.048 $/kg	12%

Approximately 75 kWh of electricity is used in processing 1 tonne of guar seed for different processing stages such as turning the vessel, sieving, etc. Wood is used as a heating source, i.e. 40 kg of wood for 1 tonne of guar seed.

Data sources:

- adapted from data provided by Sunil Kumar, Simapro India

5.16 Sweeteners

Artificial sweeteners datasets have been compiled from various sources. Sweeteners are measured on a sweetness index using bulk sugar (sucrose) as the baseline sugar with a sweetness index of 1.0. Tab. 57 shows the relative sweetness of the sweeteners covered in the WFLDB.

Tab. 57: Economic values and allocation factor used for guar seed processing products

	Sweetness index	Reference
Bulk sugar	1	
Aspartame	150	Parker et al. (2010)
HFCS 90%	Fructose has a sweetness potency of 1.3 and glucose – 0.56. HFCS 90% has a relative sweetness of 1.2.	Parker et al. (2010)
Steviosides	275	Pure Circle (2012)

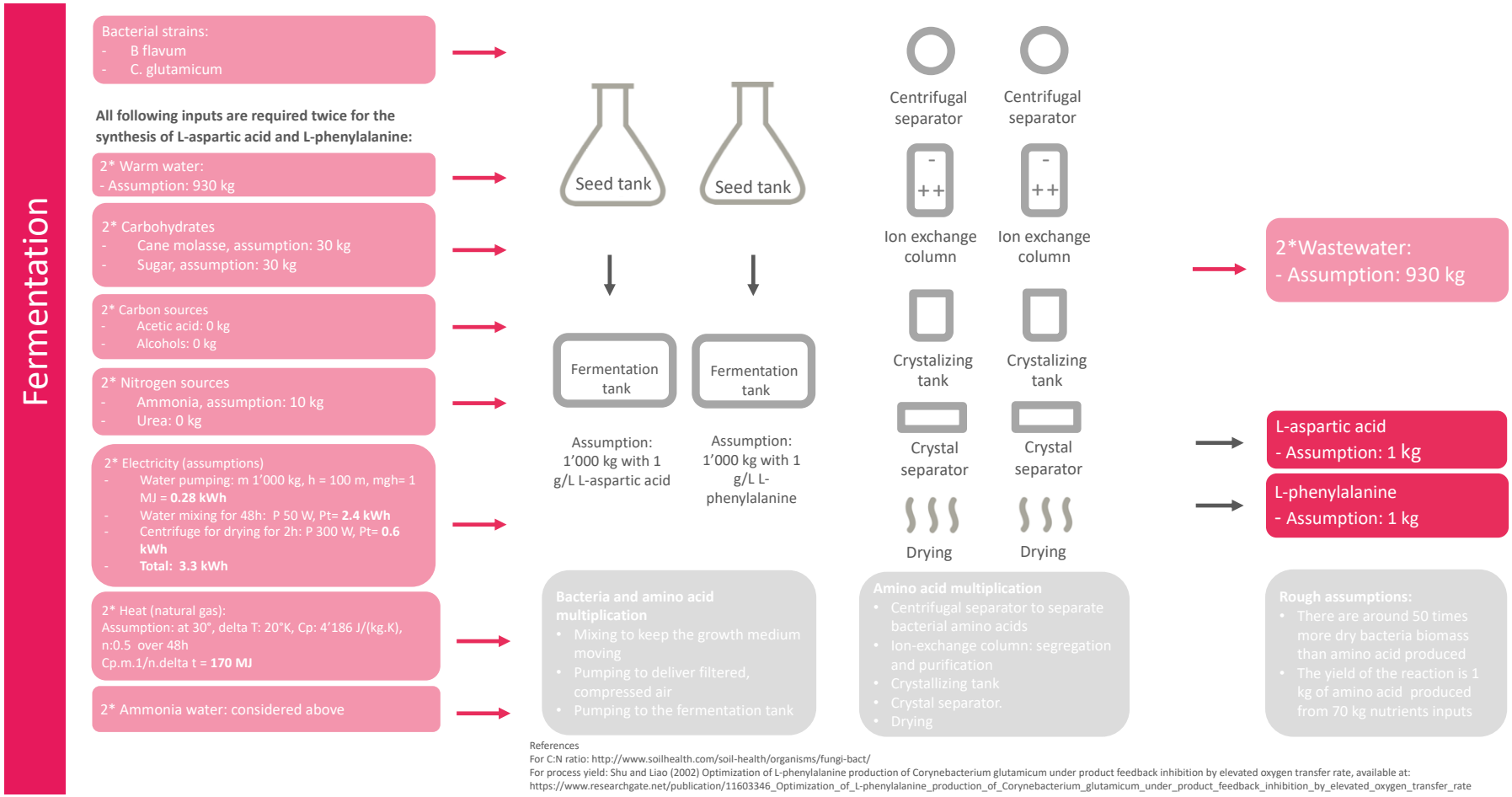
Data sources:

- Parker et al. (2010) High fructose corn syrup: Production, uses and public health concerns. Biotechnology and Molecular Biology Review Vol. 5(5), pp. 71 – 78. Available at http://www.academicjournals.org/article/article1380113250_Parker%20et%20al.pdf
- Pure Circle (2012) Carbon and water footprint: understanding and reducing impacts

5.16.1 Aspartame

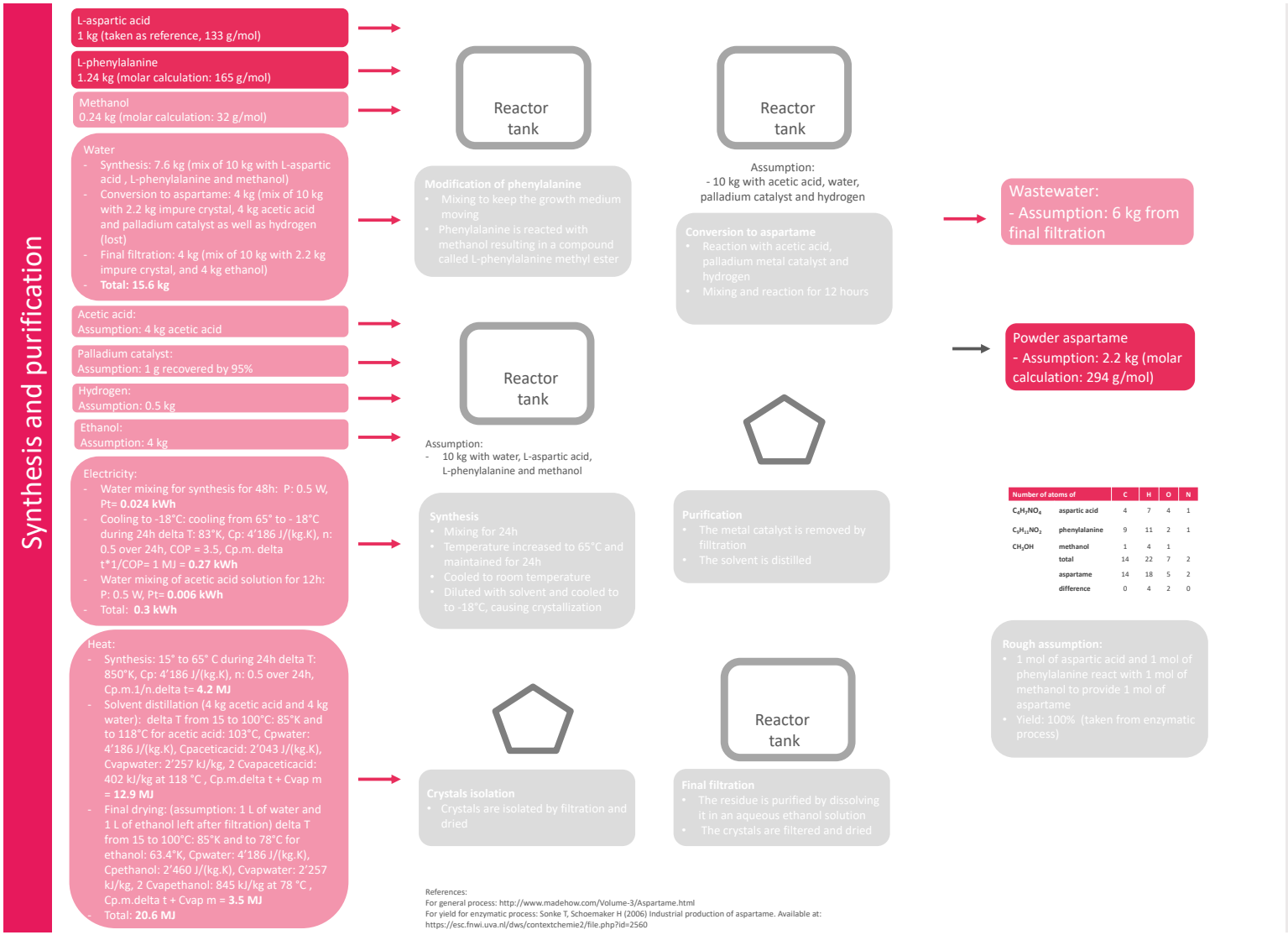
This dataset has been created based on a protocol to produce aspartame through fermentation, synthesis and purification. It corresponds to a production of aspartame through the chemical pathway. Direct fermentation produces the starting amino acids needed for the manufacture of aspartame. In this process, specific types of bacteria which have the ability to produce certain amino acids are raised in large quantities. Over the course of about three days, the amino acids are harvested and the bacteria are destroyed. Aspartame can be made by various synthetic chemical pathways. In this pathway, L-phenylalanine is modified by a reaction with methanol and then combined with a slightly modified L-aspartic acid which eventually forms aspartame. Aspartame is then purified in several stages. The process does not give co-products.

The process has a high uncertainty given that it relies mainly on a qualitative protocol complemented with assumptions. Figure 3 and Figure 4 show the main assumption for respectively the fermentation as well as the synthesis and purification stages. All inputs other than L-aspartic acid and L-phenylalamine are taken from ecoinvent 3. The impact of the production of initial bacteria strains of B. Flavum and C. Glutamicum has been neglected given that they can be continuously reused from previous batches.



References
For C:N ratio: http://www.soilhealth.com/soil-health/organisms/fungi-bact/
For process yield: Shu and Liao (2002) Optimization of L-phenylalanine production of Corynebacterium glutamicum under product feedback inhibition by elevated oxygen transfer rate, available at: https://www.researchgate.net/publication/11603346_Optimization_of_L-phenylalanine_production_of_Corynebacterium_glutamicum_under_product_feedback_inhibition_by_elevated_oxygen_transfer_rate

Figure 3: Production of aspartame, key assumptions for the fermentation stage



Number of atoms of		C	H	O	N
$C_4H_7NO_4$	aspartic acid	4	7	4	1
$C_9H_{11}NO_2$	phenylalanine	9	11	2	1
CH_3OH	methanol	1	4	1	
	total	14	22	7	2
	aspartame	14	18	5	2
	difference	0	4	2	0

Figure 4: Production of aspartame, key assumptions for the synthesis and purification stages

5.16.2 Corn glucose syrup and High Fructose Corn Syrup (HFCS)

This dataset has been developed based on various literature data for HFCS produced from corn. The corn glucose syrup is an intermediary product in the production of HFCS. HFCS is classified according to its fructose content: HFCS-42, HFCS-55 and HFCS-90 have fructose content of 42%, 55% and 90%, respectively. The starch enzymatic hydrolysis dataset is fully built by Quantis based on available literature, stoichiometric calculation, partial data from Tereos-Syral (2014) and industrial data from starchprojectsolution.com.

The corn grain undergoes several unit processes starting with steeping to soften the hard corn kernel followed by wet milling and physical separation into corn starch (from the endosperm); corn hull (bran) and protein and oil (from the germ). Corn starch composed of glucose molecules of infinite length, consists of amylose and amylopectin and requires heat, caustic soda and/or hydrochloric acid plus the activity of three different enzymes to break it down into the simple sugars, glucose and fructose, present in HFCS. In the first enzymatic step, an industrial enzyme, alpha-amylase produced from Bacillus spp., hydrolyses corn starch to short chain dextrins and oligosaccharides. A second enzyme, glucoamylase (also called amyloglucosidase), produced from fungi such as Aspergillus, breaks dextrins and oligosaccharides to the simple sugar glucose. The product of these two enzymes is corn syrup, also called **glucose syrup**. The alpha-amylase and glucoamylase used in HFCS processing have been genetically modified to improve their heat stability for the production of HFCS.

The third and relatively expensive enzyme used in the process is glucose isomerase (also called D-glucose ketoisomerase or D-xylose ketolisomerase), that converts glucose to fructose. Whereas inexpensive alpha-amylase and glucoamylase are used only once, glucose isomerase is reused until it loses most of its enzymatic activity. Corn glucose syrup is transformed into HFCS-42 through this enzymatic reaction. It can either be used as such in processed foods or further refined into HFCS-90 through liquid chromatography (separation of fructose and glucose by circulating in a specific material or membrane). The separation of glucose from fructose produces a high glucose-content raffinate that is reinjected into the HFCS-42 production process, replacing corn glucose syrup. Allocation of this process is calculated based on 2017 data from USDA's "Sugar and Sweeteners Yearbook Tables". Given the little availability of quantitative data on chromatography step, it is modelled as a conservative estimate of the electricity required to bring the glucose syrup through the column. HFCS-90 can be used as such, crystallized into crystalline fructose, or blended with HFCS-42 to obtain HFCS-55 which is mainly used in soft drinks.

The alpha-amylase, glucoamylase and glucose isomerase production is modelled with an estimate of the soybean meal and the heat required for the enzyme growth based on Nielsen et al 2007.

Data sources:

- Parker et al. (2010) High fructose corn syrup: Production, uses and public health concerns. Biotechnology and Molecular Biology Review Vol. 5(5), pp. 71 – 78. Available at http://www.academicjournals.org/article/article1380113250_Parker%20et%20al.pdf
- Hobbs, L. (2009). Sweeteners from Starch. In Starch (pp. 797–832). Elsevier. https://doi.org/10.1016/b978-0-12-746275-2.00021-5
- Galitsky C, Worell E, Ruth M (2003) Energy Efficiency Improvement and Cost saving opportunities for the corn wet milling industry. Available at https://escholarship.org/content/qt34h4p4fr/qt34h4p4fr.pdf
- Data collected from Tereos-Syral, 2014.
- http://www.starchprojectsolution.com/syrup_processing_plant/
- Nielsen PH, Oxenbøll KM, Wenzel H (2007) Cradle-to-Gate Environmental Assessment of Enzyme Products Produced Industrially in Denmark by Novozymes A/S. Int J Life Cycle Assess 12:432–438. doi: 10.1065/lca2006.08.265.1
- Dupont (2020) Chromatographic Separation of Fructose and Glucose with AmberLite™ CR99 Ion Exchange Resins Technical Manual. Available at https://www.dupont.com/content/dam/dupont/amer/us/en/water-solutions/public/documents/en/45-D02252-en.pdf
- USDA (2021) Sugar and Sweeteners Yearbook Tables, Available at: https://www.ers.usda.gov/data-products/sugar-and-sweeteners-yearbook-tables/sugar-and-sweeteners-yearbook-tables/ (Accessed: May 2021).

5.16.3 Steviosides

The steviosides extraction from dried stevia leaves is modelled according to a lab protocol described in Rao et al. 2012. It corresponds to several steps of extraction in hot water, precipitation, ultrafiltration, nanofiltration and spray drying. The powder contains still a small fraction of water (around 3%). The stevia leaves input and their transport to the factory are excluded, as well as the packaging of the finished product. Dried stevia leaves are assumed contain 10% water and the DM content of steviosides is assumed to be 11% based on Serfaty et al. 2013. Therefore 11.1 kg of dried stevia leaves at 10% moisture are needed per kg of stevioside powder dry matter.

The inventory includes the addition of deionised water, the hydrochloric acid and sodium hydroxide used to correct pH, the energy consumed for the heating and filtration and the evaporation and spray drying process. The successive steps, based on Rao et al. 2012, are:

1. Grinding of the dried leaves: the energy consumed for this step is neglected.
2. Steviosides extraction: deionised water is added to the dried ground leaves (10 kg water per kg dried leaves), HCl is added to reach a pH of 3, then the solution is heated up to 60°C and maintained at this temperature for 6 hours, then it is heated up to 105°C for 10 minutes. Natural gas is assumed to be used for the heating energy.
3. Cooling and pH adjustment: the solution is cooled. A COP of 3 is assumed for standard electric cooling system. It is assumed the solution is cooled to 20°C. NaOH is added to increase pH from 3 to 10.
4. Precipitation and filtering: the solution is heated to 60°C for 1 hour, then filtered and neutralized at pH 7 adding HCl.
5. Ultrafiltration: the solution is filtrated through a membrane 30 kPa, at room temperature. The permeate is kept. 1 of the 11% of steviosides content is lost in the retentate, together with the remaining dry matter. The energy consumption for this step is approximated based on Bahnasawy et al. 2010.
6. Evaporation: this step is added compared to the process described by Rao et al. 2012 in order to have a lower volume to send to nanofiltration. This process evaporates 95% of the water remaining after ultrafiltration.
7. Nanofiltration: the solution is filtrated through a membrane 1500 kPa at room temperature. The retentate is kept, while the nanofiltration removes 85% of the remaining water. The energy consumption for this step is approximated based on Cissé et al. 2011.
8. Activated carbon: the solution passes through activated carbon and ciliate. Only the energy consumption for this step is considered.
9. Spray drying: the same process as spray drying for milk powder is considered.

Data sources:

- Rao A B, Prasad E, Roopa G, Sridhar S, Ravikumar Y V L, 2012. Simple extraction and membrane purification process in isolation of steviosides with improved organoleptic activity. Advances in bioscience and biotechnology, 3, 327-335. Available on https://file.scirp.org/pdf/ABB20120400003_65485756.pdf
- Bahnasawy A h, Shenana M E, 2010. Flux behaviour and energy consumption of ultrafiltration (UF) process of milk. Australia Journal of Agricultural Engineering, 1 (2).
- Cissé M, Vaillant F, Pallet D, Dornier M, 2011. Selecting ultrafiltration and nanofiltration membranes to concentrate anthocyanins from roselle extract (Hibiscus sabdariffa L.). Foor Research International 44.
- Serfaty M, Ibdah M, Fischer R, et al (2013) Dynamics of yield components and stevioside production in Stevia rebaudiana grown under different planting times, plant stands and harvest regime. Ind Crops Prod 50:731–736. doi: 10.1016/j.indcrop.2013.08.063

5.17 Food additives

5.17.1 Monosodium glutamate

The dataset has been created based on a protocol to produce monosodium glutamate through fermentation, synthesis and purification detailed in Figure 5 and Figure 6.

The reference flow is 5070 kg of monosodium glutamate (MSG), at the plant exit gate.

In 1956, a direct fermentation method to produce glutamate was introduced. The advantages of the fermentation method (e.g., reduction of production costs and environmental load) were large enough to cause all glutamate manufacturers to use the fermentation until nowadays.

The production of monosodium glutamate can be distinguished in two stages:

- Fermentation by micro-organisms
- Conversion of glutamic acid to MSG

Fermentation by micro-organisms: The usual culture medium for glutamic acid fermentation contains a carbon source such as glucose, the acid hydrolysate of starch, molasses, or a mixture of these substances. A nitrogen source such as urea, and other chemicals is present. The prepared culture medium is sterilized in a fermentor by steam. When the temperature of the medium cools down to 30°C, the micro-organism is added to the fermentor in a proper inoculum size. A glutamic acid producing micro-organisms is incubated for thirty-six to forty-eight hours during which time the pH, temperature, and aeration rate are carefully controlled. When the fermentation is finished, the fermentation broth is hydrolyzed with hydrochloric acid. Glutamic acid is obtained in a process analogous to that for the recovery from the protein hydrolysate.

Conversion of glutamic acid to MSG: The crude, crystalline glutamic acid is first suspended in water and then dissolved, neutralized and converted to the monosodium salt by the addition of sodium hydroxide. The solution is decolorized using activated carbon, if necessary, and concentrated under vacuum at 60°C before cooling for crystallization. The crystals are isolated by centrifugation and then dried.

The process has a high uncertainty given that it relies mainly on a qualitative protocol complemented with assumptions. Figure 5 and Figure 6 show the main assumption for respectively the fermentation as well as the synthesis and purification stages. The impact of the production of initial bacteria strains such as Corynebacterium glutamaticum or micrococcus glutamicus has been neglected given that they can be continuously reused from previous batches.

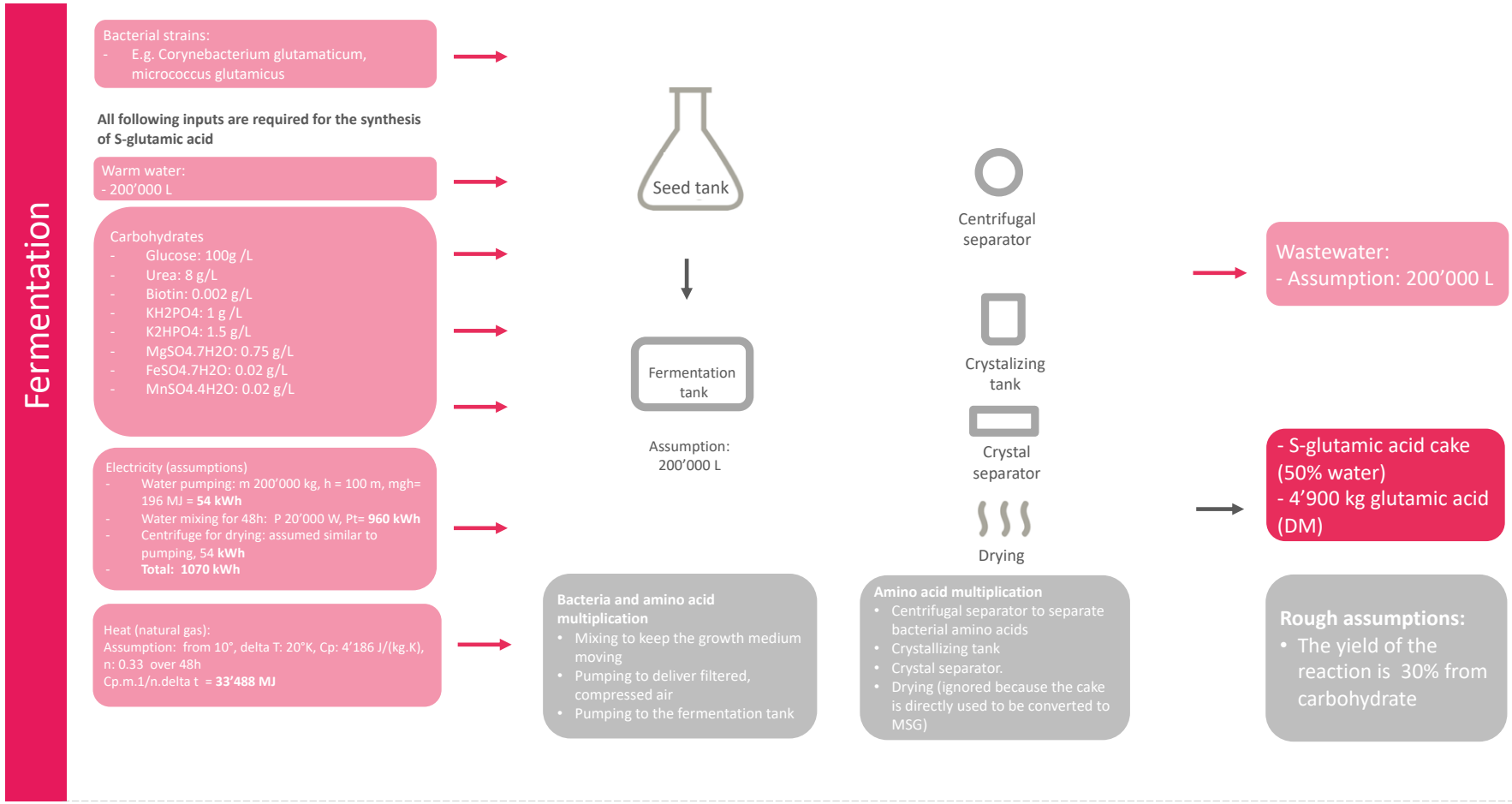


Figure 5: Production of monosodium glutamate, key assumptions for the fermentation stage

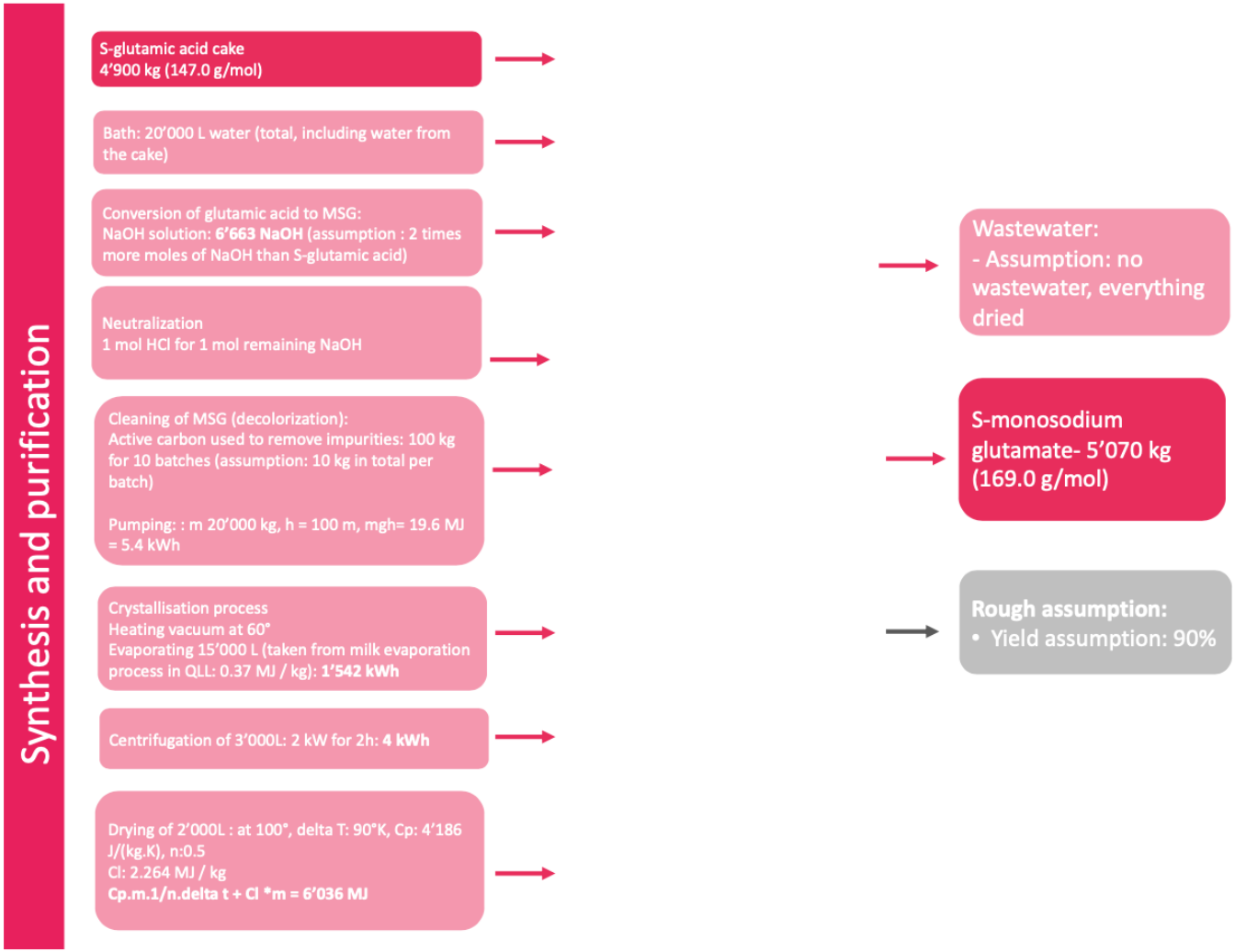


Figure 6: Production of monosodium glutamate, key assumptions for the synthesis and purification stages

Data sources:

- Sano C (2009). History of glutamate production, The American Journal of Clinical Nutrition, Vol 90 (3).
- Li T-H (1965). The production of glutamic acid by fermentation. Master Thesis at Missouri University of Science and Technology, Department of Chemical and Biochemical Engineering. Downloaded on The production of glutamic acid by fermentation, August 2019.
- Kinoshita S (1957). Studies on the amino acid fermentation. Part I. Production of L-glutamic acid by various microorganisms. J. Gen. Appl. Microbiol. Vol 3 (3), 193-205.
- Ault A (2004). The Monosodium Glutamate Story: The Commercial Production of MSG and Other Amino Acids. J Chem Educ, Vol 81 (3).
- Shyamkumar R, Ganesh Moorthy I M, Ponmurugan K, Baskar R (2014). Production of L-glutamic Acid with Corynebacterium glutamicum (NCIM 2168) and Pseudomonas reptilivora (NCIM 2598): A Study on Immobilization and Reusability. Avicenna J Med Biotechnol, Vol 6 (3), 163-168.

5.18 Fruit juice concentrates

Frozen Concentrated Juice (FCJ) is a widespread processing technique to store and transport fruit juice in a safe and efficient way. FCJ is produced from fruit juice while other co-products are generated from other fruit parts.

The concentration is usually measured in °Brix which corresponds to the total soluble solids in the juice or concentrate. These soluble solids are primarily sugars: sucrose, fructose, and glucose. Citric acid and minerals in the juice also contribute to the soluble solids. Brix is reported as "degrees Brix" and is equivalent to a percentage. For example, a juice which is 12 degrees Brix has 12% total soluble solids (Matthews 1994).
Figure 7 shows the steps in the production of concentrated orange juice.

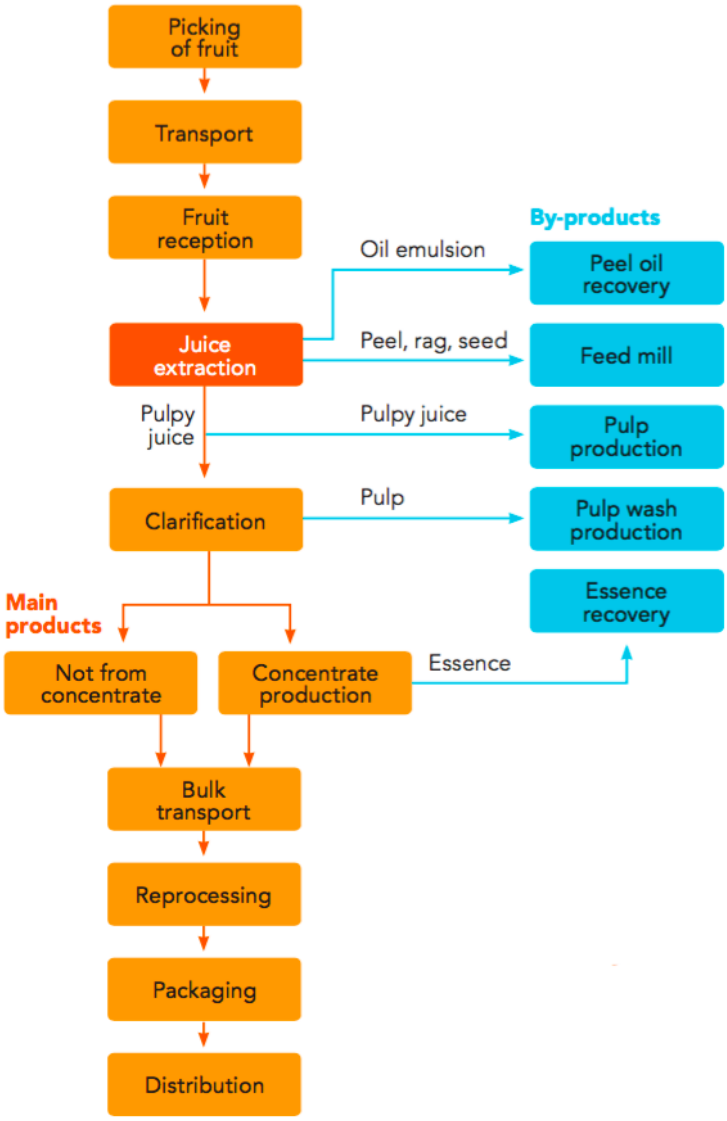


Figure 7: Steps in the production of frozen concentrated orange juice (Tetra Pak International S.A. 2017).

5.18.1 Frozen concentrated orange juice, 65° Brix

The dataset of frozen concentrated orange juice is based on processing data from Knudsen et al (2011) that focuses on the production of oranges, processing and transport of the orange juice originating from Brazil and imported to Denmark. Figure 8 shows the main inputs according to this study.

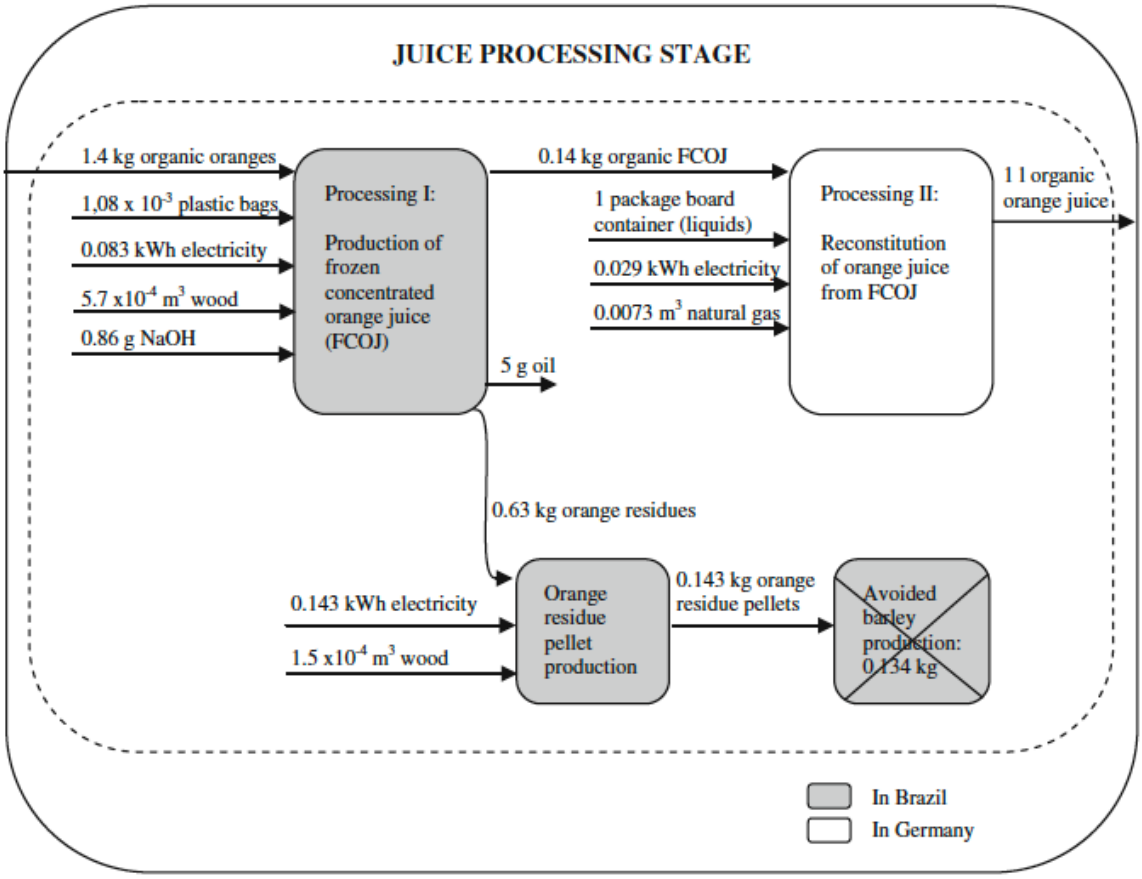


Figure 8: Resource flows in the juice processing stage in the FCOJ in Brazil (Knudsen et al. 2011)

In the WFLDB dataset, wood (coming from orange trees) is not considered as the main source of thermal energy as it is in Knudsen et al. 2011. Natural gas has been chosen as the main source as it has been judged more representative of a global worldwide situation. Plastic bags are neglected.

Several co-products of the juice processing are considered, following an economic allocation:

- Animal feed (citrus peels), from frozen concentrated orange juice production: used to produce food pellets that can replace grain feed such as barley (7% of the turnover)
- Aseptic orange pulp, from frozen concentrated orange juice production (5% of the turnover)
- Essential oils, from frozen concentrated orange juice production (2% of the turnover)
- D-limonene, from frozen concentrated orange juice production, a liquid hydrocarbon that can be used for different applications, e.g. as a dietary supplement or as a fragrance ingredient for cosmetics products (1% of the turnover)

All co-products amounts and economic values are taken from Doublet et al (2013), where 85% of the turnover is generated by not-for-concentrate orange juice. The allocation factor is based on the latter turnover values. In the latter study, there are 2.29 kg oranges / kg not-for-concentrate juice while we have in this process 10 kg oranges / kg frozen concentrate orange juice.

5.18.2 Frozen concentrated lemon juice, 47° Brix

Given low data availability for frozen concentrated lemon juice processing and co-products, the processing data for frozen concentrated orange juice production (Knudsen et al. 2011) and its co-products (Doublet et al. 2013) are taken as a proxy (per kg of processed fruit for processing).

It was estimated that 15.9 kg of lemons are required to produce 1 kg of frozen lemon concentrate, given that juice that can be extracted from lemon represents 42% of the lemon weight (Hegger and Haan 2015), and that typical ° Brix values for not-for-concentrate lemon juice are 7 according to the standards of the Association of International Juice & Nectar Producers (AIJN) and 47 for frozen concentrated lemon juice.

5.18.3 Frozen concentrated apple juice, 70° Brix

Given low data availability for frozen concentrated apple juice processing, the processing data for frozen concentrated orange juice production (Knudsen et al. 2011) are taken as a proxy per kg of processed fruit.

Apple pomace is considered as a co-product of the juice processing following an economic allocation. Apple pomace represents about 25% of apples processed for juice (Heuzé et al 2018). The values of concentrated apple juice and apple pomace are respectively considered as 0.991 $/kg (Choi 2017) and 0.3 $/kg dry = 0.09 $/kg wet (Apple pomace contains 70% water (Kruczek et al 2016)).

It was estimated that 9.6 kg of apples are required to produce 1 kg of frozen apple concentrate, given that juice that can be extracted from apple represents 73% of the apple weight (Hegger and Haan 2015), and that typical ° Brix values for not-for-concentrate apple juice are 10 according to the standards of the Association of International Juice & Nectar Producers (AIJN) and 70 for frozen concentrated apple juice.

5.18.4 Frozen concentrated grape juice, 68° Brix

Given low data availability for frozen concentrated grape juice processing, the processing data for frozen concentrated orange juice production (Knudsen et al. 2011) are taken as a proxy per kg of processed fruit.

Grape pomace is considered as a co-product of the juice processing following an economic allocation. Wet grape pomace represents between 25 and 45% of the fresh berry (Wadhwa and Bakshi 2013). The values of concentrated grape juice and grape pomace are respectively considered as 1.89 $/kg (Agribusiness intelligence 2018) and 0.3 $/kg dry = 0.21 $/kg wet (estimate as an average between no value (ACYVIA database covering France) and 0.43 $/kg wet (sale price from a company located in Russia in 2018)

It was estimated that 6.1 kg of grapes are required to produce 1 kg of frozen grape concentrate, given that juice that can be extracted from grape represents 83% of the grape weight (Hegger and Haan 2015), and that typical ° Brix values for not-for-concentrate grape juice are 13.5 according to the standards of the Association of International Juice & Nectar Producers (AIJN) and 68 for frozen concentrated apple juice.

5.18.5 Other frozen concentrated juices

The frozen concentrated juices are built considering the amount of fresh fruit needed per kg of frozen concentrated juice and the processing. The processing of the concentrate is based on the orange frozen concentrate processing assuming a similar process (see section 5.18.1). The processing dataset being per kg fresh fruit, it is adapted to the amount of fruit input. A transport of the fruits is added considering the same distance as for oranges, i.e., 120 km (Knudsen et al. 2011). The water evaporated is also added considering the fruit juice and pomace produced to obtain the fresh juice and the amount of fresh juice for 1 kg frozen concentrate.

The amount of fresh fruit needed for 1 kg of frozen concentrated juice is based on:

- the Brix level of the fresh juice
- the Brix level of the frozen concentrated juice
- the amount of fresh fruit needed per kg of fresh juice (see section 5.20)

Tab. 58: Brix level in fresh fruits, juices, and concentrated juices

Fruit	Brix level		
	Fresh fruit[1]	Juices[2]	Concentrated juices
Banana	10	22	70 [3]
Cherry	8	17	65 [4]
Mango	6	13	65 [5]
Peach	10	10.5	65.5 [4]
Pineapple	12	12.8	60 [4]
Tomato	4	5	30 [6]

[1] http://www.brixlevel.com/Fruit-and-Vegetable-Tables.do
[2] https://www.rahalfandf.com/brix-calculator
[3] https://ititropicals.com/blog/banana-juice-concentrate-70-brix
[4] https://lemonconcentrate.com
[5] https://www.kiril-mischeff.com/product/mango-juice-concentrate
[6] http://mercofood.cl/tomatoconcentrate

5.19 Fruit juice concentrates dilution: from concentrate juices

A dilution process is built considering the energy needed for that process (heat and electricity). These are based on the from orange juice from frozen concentrate dilution process from Knudsen et al. 2011. The dilution water depending on each fruit and the Brix level to be obtained, it is added in the processes of fruit juice from concentrate directly, together with the frozen concentrate input and not directly in the dilution process.

The dilution is done for 1 kg output juice and considers the following inputs: 0.0279 kWh electricity and 0.255 MJ heat from natural gas per kg juice produced.

The amount of frozen concentrate and of dilution water per kg of fruit juice from concentrate is based on the Brix level of the concentrate and of the diluted juices (see table of the previous section).

5.20 Fresh fruit juices

The fresh fruit juices are built considering the amount of fresh fruit needed as well as processing step and a transport of the fruits (120 km assumed based on Knudsen et al. 2011).

The processing of fruits into not from concentrate (NFC) juices includes the energy for the processing only (electricity, natural gas, diesel and petrol) based on Diwedi et al. 2012. Water or chemicals for fruit washing or equipment cleaning are not included. The input of fruits is not included in the processing but in the not from concentrate juices datasets.

The amount of fresh fruit for 1 kg of juice is based on various data sources, considering the non-edible parts of the fruits and the juice yield, or Brix levels in fruit and juice when no yield was available.

Tab. 59: Amount of fresh fruit per kg of juice

Fruit	kg fresh fruit / kg juice	References
Banana	2.45	- Mass of a peeled banana represents 71% of the total mass of the banana (http://questionmark-assets.s3.amazonaws.com/2014/03/Questionmark-Environmental-impact-study-Juice.pdf) - Optimum yield for mechanical juice extraction from peeled banana is 57.5% (Majaliwa 2019)
Cherry	2.39	- Brix level final product: 17° Brix (https://www.rahalfandf.com/brix-calculator) - Average amount of sugar in a cherry: 8° Brix (http://brixlevel.com/Fruit-and-Vegetable-Tables.do) - Between 7% and 15% of the cherry corresponds to the seed (Yilmaz 2019)
Mango	2.49	- Mango pulp represents between 33% and 85% of the entire mango (Buenrostro-Figueroa 2010). - For a 12-13°Brix juice, the mechanical extraction yield is around 68% (Buenrostro-Figueroa 2010).
Peach	2.04	Juice yield: 49% (Source: http://questionmark-assets.s3.amazonaws.com/2014/03/Questionmark-Environmental-impact-study-Juice.pdf, page 20)
Pineapple	1.54	Juice yield: 65% (http://questionmark-assets.s3.amazonaws.com/2014/03/Questionmark-Environmental-impact-study-Juice.pdf, corresponds to the average from 4 studies, range being 51% to 75%).
Tomato	1.37	- 4% of the tomato is not processed (peel, seeds) (Zuorro 2013) - Brix level final product: 5° Brix (https://www.rahalfandf.com/brix-calculator) - Average amount of sugar in tomatoes: 4° Brix (http://brixlevel.com/Fruit-and-Vegetable-Tables.do) - 5% of losses based on expert judgment

Data sources:

- Agribusiness intelligence. 2018 Some Spanish white grape juice prices fall. Available at https://iegvu.agribusinessintelligence.informa.com/CO215147/Some-Spanish-white-grape-juice-prices-fall
- Buenrostro-Figueroa J, de la Garza-Toledo H, Ibarra-Junquera V, Aguilar C N (2010) Juice extraction from mango pulp using an enzymatic complex of Trichoderma sp. produced by solid-state fermentation. Food Sci. Biotechnol. 19(5): 1387-1390
- Choi 2017. Apple Juice Concentrate. Apple crop outlook and marketing conference. Available on http://usapple.org/wp-content/uploads/2017/08/AppleJuicePanel_MichaelChoi.pdf
- Dwivedi, Puneet & Spreen, Thomas & Goodrich-Schneider, Renée (2012) Global warming impact of Florida's Not-From-Concentrate (NFC) orange juice. Agricultural Systems, vol. 108, pages 104-111.
- Doublet G, Jungbluth N, Stucki M, Schori S, 2013 SENSE 'HarmoniSed Environmental Sustainability in the European food and drink chain', Deliverable: D2.1 Life cycle assessment of orange juice
- Hegger S and Haan G. 2015 Environmental impact study of juice. Report by Questionmark
- Heuzé V, Tran G, Hassoun P, Lebas F, 2018. Apple pomace and culled apples. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/20703 Last updated on July 10, 2018, 16:28
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- Kruczek M, Drygas B, Habryka C, 2016. Pomace in fruit industry and their contemporary potential application . World Scientific News 48 (2016) 259-265
- Majaliwa N, Kibazohi O, Alminger M (2019) Optimization of process parameters for mechanical extraction of banana juice using response surface methodology. Journal of Food Science and Technology volume 56, 4068–4075
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- Tetra Pak International S.A. (2017) The Orange Book. Available on https://orangebook.tetrapak.com/chapter/fruit-processing
- Wadhwa M and Bakshi MPS. 2013. Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products. FAO report
- Yilmaz, F M, Görgüç A, Karaasian M, Vardin H (2019), Sour Cherry By-products: Compositions, Functional Properties and Recovery Potentials – A Review. Critical Reviews in Food Science and Nutrition 59 (22), 3549-3563
- Zuorro A, Lavecchia R, Medici F, Piga L (2013). Enzyme-assisted production of tomato seed oil enriched with lycopene from tomato pomace. Food and Bioprocess Technology, 6, 3499-3509
- http://www.brixlevel.com/Fruit-and-Vegetable-Tables.do
- https://www.rahalfandf.com/brix-calculator
- https://ititropicals.com/blog/banana-juice-concentrate-70-brix
- https://lemonconcentrate.com
- https://www.kiril-mischeff.com/product/mango-juice-concentrate
- http://mercofood.cl/tomatoconcentrate
- http://questionmark-assets.s3.amazonaws.com/2014/03/Questionmark-Environmental-impact-study-Juice.pdf
- https://mango-trees.blogspot.com/2020/10/mango-waste-pomace-and-peel.html
- https://www.zumosygazpachos.com/asozumos/libro-del-zumo/descargate-el-libro-del-zumo_3336_167_11126_0_1_in.html

5.21 Processed fruits

5.21.1 Dehydrated fruits/dried fruits

Dehydration allows for conservation of fresh fruits and vegetables. The product is usually dehydrated from 80% water content to less than 25% water content. The water can be extracted through different techniques. The most used technique worldwide is hot air drying (85% of production). In some countries, and for some fruits, solar drying is also a strong alternative, with low costs if the sun power and air humidity allows for such technique. Freeze drying and osmotic drying are also two alternatives that are getting increasingly used, however still marginal compared to the previous two. All dehydrated fruits are considered to be hot air dried, but the water content before and after drying will affect the energy needed to achieve the desirable water content. Note that some fruits can often be freeze dried, or osmotic dried, which is are more energy or material intensive processes.

These datasets account for the input for fruits, post-processing energy & water consumption, storage of the fresh fruit energy consumption, and the drying operations (Frankowska 2019). They do not account for chemicals used in preservation or ripening, packaging and food waste in storage & processing. Fruits are considered as local and import distances should be added as these can have a significant impact. Water content of fresh fruits are taken from (Health Matters Program 2011) and water content of dried fruits are taken from (UNECE 2021) for apple and apricot, (USDA) for raisins and (Dorofejeva 2011) for berries.

The food waste while grading and storing fresh fruits and then processing is modelled and aggregated into a $food_waste$ parameter.

The amount of evaporated water is equal to the amount of fresh fruits entering the processing stage minus the amount of dried fruits (1 kg):

$$m_{water} = \frac{w_f - 1}{w_i - 1} * \frac{1}{processing_waste} - m_{dry}$$

Where "*processing_waste*" is the food waste rate during the processing stage, and m_{dry} is the final amount of dried fruits (1 kg).

Total food waste is the difference between the total amount of fresh fruits "m_{fruits}" and "m_{water}+m_{dry}".

Water is used to clean the fresh fruits (0 to 2L per fresh product, depending on the fruit) and in the dehydration process (2L per kg dried product).

The following dried fruits have been developed as first averages for the global market:

- Dehydrated apple
- Dehydrated apricot
- Dehydrated strawberry (also available for US strawberries)
- Dehydrated grape, or raisins (also available for US grapes)
- Dehydrated cranberry

Data sources:

- Frankowska, A., Jeswani, H., & Azapagic, A. (2019). Life cycle environmental impacts of fruits consumption in the UK. *Journal Of Environmental Management*, *248*, 109111. https://doi.org/10.1016/j.jenvman.2019.06.012
- Health Matters Program. (2011). Water Amounts in Fruits and Vegetables. Adapted from Water Content of Fruits and Vegetables
- UNECE (2021), Dry and Dried Produce – Standards, https://unece.org/trade/wp7/DDP-Standards Accessed on June 2021.
- Dorofejeva, K., Rakcejeva, T., Galoburda, R., Dukalska, L., & Kviesis, J. (2011). Vitamin C content in Latvian cranberries dried in convective and microwave vacuum driers. Procedia Food Science, 1, 433-440. doi: 10.1016/j.profoo.2011.09.067
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5.22 Plant-based drinks

Two kinds of plant-based drinks (alternatives to dairy milk) production datasets have been developed, describing the production of oat and almond drinks. The two datasets describe plant material input (oat/almond), energy consumption and transportation as well as wastewater treatment and other waste treatment of residual waste. The specificities of each system are described in the following sections.

5.22.1 Oat drink

This multi-output process covers the production oat drink and oat residues. It is based on data from the brand Oatly and the factory located in Landskrona, Sweden reported in Ahlberg et al. (2017).

For 1000 L of oat drink produced, 20 kg of dry oat fiber are removed. This co-product includes oat residues at the mill which are used for cattle food production and products which have not been sold, damaged or used for quality assessment are used for biogas production.

The economic values used for the allocation were calculated as follows:

- Oat drink: average sale price 2 EUR / L (https://www.amazon.de/Oatly-Bio-OATLY-Haferdrink-Original), expert judgement: 1 EUR / L for raw unpackaged product
- Oat residues: average between soybean meal (297 EUR / t) and rape seed cake (174 EUR/t) value (Schneider and Finkbeiner 2013)

The functional unit is 1 litre of oat drink, at plant. At the factory, the oat seeds are first milled together with water and treated with enzymes. Unwanted oat residues in the mix are then filtered out. The remaining mix is blended with rapeseed oil and sodium chloride (Röös et al., 2016). These are all transported by truck to the factory in Landskrona. The liquid is treated with heat to prolong durability. The energy used is natural gas and electricity. The process also uses chemicals to clean equipment: sodium hydroxide and nitric acid (Floren et al., 2013). There are several waste streams from this process. The oat residues are separated and used for cattle food production (Röös et al., 2016). There is also waste related to quality inspections and unsold products. These waste streams are used to produce natural gas (Floren et al., 2013).

Data sources:

- Ahlberg et al. 2017 Life cycle analysis - a comparison between oat drink and conventional milk, Thesis.

- Schneider and Finkbeiner (2013) Life Cycle Assessment of EU Oilseed Crushing and Vegetable Oil Refining, commissioned by Fediol. Report from the Technical University of Berling, Chair of Sustainable Engineering. Downloaded on
- www.fediol.eu/data/1521124882Full%20FEDIOL%20LCA%20report_05062013_CR%20statement.pdf, August 2019
- Röös E, Patel M, Spangberg J (2016). Producing oat drink or cow's milk on a Swedish farm – Environmental impacts considering the service of grazing, the opportunity cost of land and the demand for beef and protein. Agricultural Systems 142, 23-32.
- Floren B, Nilsson K, Wallman M (2013). LCA on fresh and aseptic oat drink. The Swedish Institute for Food and Biotechnology, Gothenburg, Sweden.

5.22.2 Almond drink

The production of almond drink starts with the processing of almond kernels into an almond paste by grinding and heating. During the process, almond kernels are dried, and their moisture content is reduced from 6 to 3%. The almond paste is transported to the almond drink manufacturing facility, where it is dispersed in water (almond content 2.3%), together other additives, such as salt, soybean lecithin and sugar, and the dispersion is mixed and heated. Information on the energy consumption during dispersion (electricity and heat) is retrieved from the ecoinvent dataset that describe the mixing activity of soybean beverage production. Efficiency of 100% is considered in the process, with no residual almond or water.

Two almond drink datasets are generated, to describe a sweetened and unsweetened version: *Almond drink, unsweetened, at plant (WFLDB)/GLO U* and *Almond drink, sweetened, at plant (WFLDB)/GLO*. The considered recipe is based on the composition of Alpro almond drinks (available online) and a European Patent Application report on the methods of almond drink production.

Transportation of almond kernels from the shelling and hulling facility to the processing plant, and afterwards to the almond drink production facility is included in the inventory. Information on the almond and almond drink production in California, a major almond producing country, is used to describe the average global production line of almond beverage. A distance of 100km for each route is taken into account.

Data sources:

- Henderson A. and Unnasch S. (2017) Life Cycle Assessment of Ripple Non-Dairy Milk. Life Cycle Assoc 1–24
- Grant CA, Hicks AL (2018) Comparative Life Cycle Assessment of Milk and Plant-Based Alternatives. Environ Eng Sci 35:1235–1247. doi: 10.1089/ees.2018.0233
- California Almonds (2014) technical summary: www.almonds.com/sites/default/files/content/attachments/2014aq0007_shelf_life_factors.pdf
- Alpro sweetened almond drink product recipe: https://www.alpro.com/de/produkte/drinks/mandeldrinks/original
- Alpro unsweetened almond drink product recipe: https://www.alpro.com/de/produkte/drinks/mandeldrinks/ungesuesst
- European Pattent Office - 2 399 608 A1 (2013) European Patent Application. J Chem Inf Model 53:1689–1699. doi: 10.1017/CBO9781107415324.004

5.23 Tea processing

The tea processing datasets include the energy, water, chemical inputs as well as the wastewater and other wastes treatment. The input of tea is included in the processing datasets to obtain black or green tea.

The same fresh tea leaves are used as input for black and green tea. The differences in the processing steps lead to two different final products.

5.23.1 Black tea

Datasets created: Black tea, at plant (WFLDB)/CN U, Black tea, at plant (WFLDB)/KE U and Black tea, at plant (WFLDB)/LK U

The steps for black tea processing are withering, rolling, oxidation, drying and sorting. The heat from wood, coal and diesel is included, as well as the electricity, chemical consumption, water use and the wastewater and other wastes treatment. The packaging of the finished product is excluded. There are 4.58 kg of fresh tea leaves input for 1 kg dry black tea produced (Azapagic 2013, Mitra 2016 and Taulo 2016) and losses of tea are of 2.6 g of dried material/kg of made tea (Taulo 2016). The total fresh tea leaves input is therefore 4.59 kg/kg dried black tea (finished product).

The same processing is considered for the 3 countries and only the electricity mixes as well as the water emissions to air flow are regionalized. Data come from various literature sources on processing in various countries: India, Kenya, Sri Lanka, Malawi mostly. The processing flows are described in Tab. 60.

Tab. 60: Black tea processing

	Amount / kg processed black tea	Unit	Reference
Fresh tea leaves	4.59	kg	Azapagic 2013, Mitra 2016, Taulo 2016
Electricity	2.38	MJ	Azapagic 2013, Hadipour Zimsar 2018, Jefferies 2012, Melican 2004, Mitra 2016, Nagaraj 2015, NEDFI 2017and Taulo 2016
Heat	30.29	MJ	Jefferies 2012, Mitra 2016 and Taulo 2016
Tap water	5.55	kg	Taulo 2016
Inorganic chemicals	0.8	g	Taulo 2016
Wastewater	3.6	kg	Taulo 2016
Biowaste	2.6	g	Taulo 2016
Water emissions to air	5.53	kg	Taulo 2016

5.23.2 Green tea

Datasets created: Green tea, at plant (WFLDB)/CN U, Green tea, at plant (WFLDB)/KE U and Green tea, at plant (WFLDB)/LK U

The processing considered includes withering, steaming (to stop oxidation), drying and sorting. The heat from wood, coal and diesel is included, as well as the electricity, chemical consumption, water use and the wastewater and other wastes, mostly based on the same references as for black tea. The energy consumption is adapted to the green tea processing considering only the steps existing for the two types of treatment and adding the steaming energy consumption. As for black tea, the packaging of the finished product is excluded. The same yield as for black tea is considered: 4.59 kg fresh tea leaves/kg dry green tea (finished product). The same processing is considered for the 3 countries and only the electricity mixes as well as the water emissions to air flow are regionalized.

The processing flows are described in Tab. 61.

Tab. 61: Green tea processing

	Amount / kg processed black tea	Unit	Reference
Fresh tea leaves	4.59	kg	Azapagic 2013, Mitra 2016, Taulo 2016
Electricity	2.21	MJ	Azapagic 2013, Hadipour Zimsar 2018, Jefferies 2012, Melican 2004, Mitra 2016, Nagaraj 2015, NEDFI 2017, Singh 2014 and Taulo 2016

	Amount / kg processed black tea	Unit	Reference
Heat	38.4	MJ	Jefferies 2012, Mitra 2016, Singh 2014, Taulo 2016, and steaming machine available on https://www.delijx.com/electric-heating-continuou-tea-steaming-machine-6cstl-d60_p24.html
Tap water	8.99	kg	Taulo 2016
Inorganic chemicals	0.8	g	Taulo 2016
Wastewater	3.6	kg	Taulo 2016
Biowaste	2.6	g	Taulo 2016
Water emissions to air	8.97	kg	Taulo 2016

Data sources:

- Azapagic 2013: Azapagic A, 2013. Life cycle assessment of tea produced in Kenya. Climate change the tea sector in Kenya: Impact assessment and policy action national multi-stakeholder workshop in Naivasha. Downloaded on http://www.fao.org/fileadmin/templates/est/Climate_change/kenya/Navaisha_wkp_1/FAO_Uni_Manchester_AZAPAGIC_LCA_of_tea.pdf, June 2019.
- Hadipour Zimsar 2018: Hadipou Zimsar, S, Firouzi, S, Sadegh Allahyari, M, 2018. Enhancers of the energy efficiency in tea processing industry. Energy equipment systems, vol 6 (2).
- Jefferies 2012: Jefferies D, Mun~oz I, Hodges J, King V J, Aldaya M, Ercin A E, Mila` i Canals L, Hoekstra A J, 2012. Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine. Journal of Cleaner Production, 33, 155-166.
- Mitra 2016: Mitra S, Roy T, 2016. An energy audit in a tea manufacturing industry at North Bengal, India. International Journal of Research in Engineering and Technology, Vol 5 (6).
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- Senthil Kumar 2013: Senthil Kumar R S, Murugesan S, Kottur G, Gyamfi D, 2013. Black Tea: The Plants, Processing/ Manufacturing and Production. Tea in Health and Disease Prevention, Chapter 4, Elsevier Inc.
- Singh 2014: Singh V, Kumar Verma D, Singh G, 2014. Processing technology and health benefits of green tea. Popular Kheti, 2 (1). Downloaded on https://www.researchgate.net/publication/261547299_Processing_Technology_and_Health_Benefits_of_Green_Tea, August 2019.
- Steaming machine specifications: https://www.delijx.com/electric-heating-continuou-tea-steaming-machine-6cstl-d60_p24.html, visited on August 2019.
- Tankariwala 2004: Tankariwala N F, 2004. Technical session 2: Cost reduction in factory. In Processing tea for lower cost and better quality, Vol 3 (3&4). Downloaded on https://repository.up.ac.za/bitstream/handle/2263/8402/Part2S2_2004.pdf?sequence=1&isAllowed=y, August 2019.
- Taulo 2016: Taulo, J L, Sebitosi, A B, 2016. Material and energy flow analysis of the Malawian tea industry. Renewable and sustainable energy reviews, 56, 1337-1350.

5.23.3 Rooibos

The processing for rooibos covers the bruising, fermentation and drying (sun-drying). The transport of harvested fresh rooibos to processing facility is also considered.

There is a ratio of 3:1 from the fresh harvested rooibos to the fermented and dried rooibos final product (Bienabe et al 2008 and Mogala 2012). The rooibos is transported by truck from farm to factory over 50 km according to experts on rooibos in South African interviewed by Peterson Control Union.

Once at processing plant, rooibos is cut in small pieces and it is then transported and piled for fermentation. It is then aerated and distributed into thin layer for drying. These 2 steps are done using tractors and it is assumed a tractor is used about 1 hour for 1 tonne of rooibos. The diesel consumption for 1 h of tractor use is 14.5 L (https://hal.science/hal-00681698/document#:~:text=On%20estime%20ainsi%20que%20la,(donn%C3%A9es%20d'immatriculations).), i.e., 0.52 MJ diesel considering 0.84 kg/L and 42.8 MJ/kg (ecoinvent default values).

For fermentation, rooibos needs to be moisturised regularly, until it gets its red color and sweet taste. 10 L of water per 35 kg of plant are used according to Morton 1983, i.e., 0.86 kg water (considering the 3:1 ratio from fresh input to finished product).

The electricity consumption for the different steps is approximated based on the black tea processing (Azapagic 2013, Hadipour Zimsar 2018, Jefferies 2012, Mitra 2016, Nagaraj 2015, NEDFI 2017, Melican 2004 and Taulo 2016). For black tea, 2.38 MJ electricity are used/kg made tea. According to Taulo 2016, it was possible to determine the fraction of energy used for each step of black tea processing as electricity: 35% for withering, 30% for rolling, 7% for oxidation, 14% for drying and 14% for sorting. For rooibos, there is no withering and the drying is sun-drying, so only 51% of the electricity is assumed to be used, leading to 0.34 kWh/kg tea.

Tab. 62: Rooibos processing

	Amount / kg processed rooibos	**Unit**	**Reference**
Fresh rooibos	3	kg	Bienabe et al 2008, Mogala 2012
Transport by truck	0.15	Tkm	Transport from farm to factory: Peterson Control Union
Diesel	0.52	MJ	Assumption, ecoinvent, https://hal.science/hal-00681698/document#:~:text=On%20estime%20ainsi%20que%20la,(donn%C3%A9es%20d'immatriculations).
Electricity	0.34	MJ	Azapagic 2013, Hadipour Zimsar 2018, Jefferies 2012, Melican 2004, Mitra 2016, Nagaraj 2015, NEDFI 2017, Taulo 2016 and assumptions.
Tap water	0.86	kg	Morton 1983, Bienabe et al 2008, Mogala 201.
Water emissions to air	0.86	kg	The water used for fermentation is assumed as fully evaporated while the rooibos is sun-dried.

Data sources:

- Azapagic 2013: Azapagic A, 2013. Life cycle assessment of tea produced in Kenya. Climate change the tea sector in Kenya: Impact assessment and policy action national multi-stakeholder workshop in Naivasha. Downloaded on http://www.fao.org/fileadmin/templates/est/Climate_change/kenya/Navaisha_wkp_1/FAO_Uni_Manchester_AZAPAGIC_LCA_of_tea.pdf, June 2019.
- Bienabe E, Bramley C, Kirsten J, 2008. Diagnostic study for the promotion of beneficiated agroindustry products for export: rooibos and honeybush tea. UNIDO. Retrieved on https://agritrop.cirad.fr/552416/1/document_552416.pdf, June 2023.
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- Hadipour Zimsar 2018: Hadipou Zimsar, S, Firouzi, S, Sadegh Allahyari, M, 2018. Enhancers of the energy efficiency in tea processing industry. Energy equipment systems, vol 6 (2).
- Jefferies 2012: Jefferies D, Mun~oz I, Hodges J, King V J, Aldaya M, Ercin A E, Mila` i Canals L, Hoekstra A J, 2012. Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine. Journal of Cleaner Production, 33, 155-166.
- Melica N J T, 2004. Processing tea for lower cost and better quality, Chapter 11 in Technical session 2, Cost reduction in factory chairman NF Tankariwala, vol 3 (3&4). Retrieved on https://repository.up.ac.za/bitstream/handle/2263/8402/Part2S2_2004.pdf?sequence=1&isAllowed=y, July 2023.Mitra 2016: Mitra S, Roy T, 2016. An energy audit in a tea manufacturing industry at North Bengal, India. International Journal of Research in Engineering and Technology, Vol 5 (6).
- Nagaraj DH, 2015. Preliminary energy study conducted at Arrapetta tea factory. Part of the course EE6401 Energy audit and management, NIT Calicut. Retrieved on http://www.nitc.ac.in/electrical/ipg/PDF/INDUSTRIAL%20AUDIT/EAM3.pdf, August 2019.
- NEDFI 2017: North Eastern Development Finance Corporation Ltd (NEDFI), 2017. Project report on tea processing (mini tea factory). Downloaded on https://www.nedfi.com/sites/default/files/Project_Profile/Tea%20Processing%20%28Mini%20Tea%20Factory%29.pdf, August 2019.
- Taulo 2016: Taulo, J L, Sebitosi, A B, 2016. Material and energy flow analysis of the Malawian tea industry. Renewable and sustainable energy reviews, 56, 1337-1350.

5.24 Malt production

The barley grains are first transformed into malted barley, with the production of barley malt rootlets as co-products. The malted barley is then transformed either in crystal malt or in roast malt.

The data represent average values based on a survey among Euromalt members carried out in March 2015 in response to the Data request from the PEF-Pilot Beer Technical Secretariat.

For the malted barley and barley malt rootlets production, the inventory includes the processing water (4.8 kg/kg malted barley) and energy for the malting process (1.25 MJ steam and 1.25 MJ heat from light fuel oil per kg malted barley), as well as the barley grain input (1.3 kg input/kg malted barley). The water outputs as emissions to air and wastewater are considered following the default data for food processing from WFLDB methodological guidelines (i.e., 12.2% to air, 87.8% to wastewater treatment). An economic allocation is applied to distribute the impacts among malted barley (100%) and the barley malt rootlets (0%).

For the crystal malt and roast malt, the inventories include the malted barley input, the energy consumption and for roast malt, the tap water used. The malted barley input is 1 kg for 1 kg crystal malt or roast malt. The energy consumption is for crystal malt 1.5 MJ steam and 0.005 kWh electricity while it is higher for roast malt: 2.65 MJ steam and 0.025 kWh electricity. The tap water consumption for roast malt is 0.2 kg per kg product. The water outputs as emissions to air and wastewater are considered following the default data for food processing from WFLDB methodological guidelines (i.e., 12.2% to air, 87.8% to wastewater treatment).

Data source:

- Euromalt Secretariat: euromalt@grainindustry.com. Survey among Euromalt members carried out in March 2015 in response to the Data request from the PEF-Pilot Beer Technical Secretariat.

5.25 Nut processing

5.25.1 Walnuts

The walnuts are harvested in husk. They are then transported to a factory where the husk is removed to obtain in-shell and dried walnuts. Then another processing step enable to obtain walnut kernels. The processing takes place in the farming country included in the database, i.e., USA.

Husk removal: The dataset includes the energy consumption (electricity and natural gas), the water use and the wastewater treatment, and it excludes the walnut in shell and husk input. The green husks removed go in the

wastewater to the treatment plant. The husking and drying processing is added to the walnut cultivation dataset to obtain walnut, in-shell and dried at farm. Based on Yilmaz 2017, for fresh weight, 56.8% is for the in-shell walnut and 43.2% for the green husk and the dry in-shell walnut mass is 66.5% of the fresh in-shell walnut. Therefore 2.65 kg of fresh in husk walnut produce 1 kg of in-shell dried walnuts. Even if the process takes place in a factory outside the farm, it is coupled with the walnut cultivation in the dataset created to obtain in-shell and dried walnuts at farm. Indeed, a dataset for in husk walnuts would not be useful in the database.

Shelling: The dataset includes the electricity consumption for shelling and for 3 months of refrigerated storage. The shells are burned. The input of in-shell, dried walnuts are included.

The table below (Tab. 63) summarizes the inputs and outputs considered for these two processing steps.

Tab. 63: Walnut processing inputs and outputs

	Walnut, dehusking and drying, at plant			
		Amount	**Unit**	**Reference**
Inputs	Electricity	0.0236	kWh	Klonsky 2009
	Heat from natural gas	1.28	MJ	Klonsky 2009
	Tap water	4.7	kg	Ozdemir 2018: 3.7 to 5.7 L water used for 1 kg husked walnut.
Outputs	Water emissions to air	0.51	kg	Water evaporated through drying, corresponds to the input material (2.65), minus the husk removed (1.14 kg), minus the in-shell walnut output. Based on Yilmaz 2017.
	Wastewater, to wastewater treatment	5.84	kg	The wastewater containing the water input plus the husk mass is assumed to be treated in a wastewater treatment plant.
	Walnut, in-shell, dried	1	kg	
Walnut kernels, dried, at plant				
Inputs	Walnut, in-shell, dried	1.5	kg	Based on Amon 2012, 0.5 kg shell/kg kernel
	Electricity for shelling	0.00275	kWh	Based on Baarda 2017: use of a 800 kg/h separator machine with a nameplate power consumption of 2.2 kW
	Electricity for refrigerated storage	0.942	kWh	Based on Baarda 2017: 0.942 kWh/kg kernel for storage
OUtputs	Walnut shells to incineration	0.5	kg	The shell wastes are assumed to be incinerated
	Walnut, shelled, dried	1	kg	

Data sources:

- Amon 2012: Amon R, Jenner M, El-Mashad H, Williams R, Kafka S, 2012. California food processing industry organic residue assessment, Final project report. Energy research and development division. Downloaded on https://ww2.energy.ca.gov/2013publications/CEC-500-2013-100/CEC-500-2013-100.pdf, August 2019.
- Baarda 2017: Baarda R, Bergman S, Gonel G, 2017. Energy analysis of walnut production in California, Final report. Downloaded on https://piet.ucdavis.edu/wp-content/uploads/2013/09/Energy-analysis-of-walnut-production-in-California.pdf, August 2019.
- Klonsky 2009: Klonsky K, Thompson J, Grant J, Hasey J, Elkins R, 2009. Sample costs to hull and dry walnuts, North San Joaquin Valley, Sacramento Valley and Lake County. University of California Cooperative Extension Report. Downloaded on https://coststudyfiles.ucdavis.edu/uploads/cs_public/ea/e7/eae7d76f-92cc-4c3f-a0cf-800a0a524a15/huller-dryerstudy2009.pdf, August 2019.
- Ozdemir 2018: Ozdemir Y, Kayahan S, Utku O, 2018. Developing a system for walnut husking to reduce wastewater formation and its comparison with industrial husking system for environmental perspective. J Food Technol Pres 2018 Vol 2 (2).

- Yilmaz 2017: Yilmaz S, AkÁa Y, SaÁlik S, 2017. Green husk and Inshell biomass production capabilities of six walnut cultivars. J Internation Scientific Publications, Agriculture & Food. Vol 5.

5.25.2 Peanuts

The dataset for peanuts at farm consists of fresh peanuts in shell. They are then transported from the farm to different factories for several steps of processing. In total, 4 processing steps have been modelled. Processing takes place in the farming countries included in the database. Originally, data for processing is retrieved from a US study. To model processed peanuts in the other geographies, the electricity mix was adapted.

- Drying of fresh peanuts in shell → Peanut, in shell, dried, at plant (WFLDB)/US U
- Shelling of dried peanuts → Peanut, shelled, dried, at plant (WFLDB)/US U
- Bleaching of dried and shelled peanuts → Peanut, shelled, dried, bleached, at plant (WFLDB)/US U
- Roasting of dried, shelled and bleached peanuts → Peanut, shelled, dried, bleached, roasted, at plant (WFLDB)/US U

Peanut drying: The dataset the energy consumption (electricity, natural gas, liquid propane)

Shelling, bleaching and roasting: These datasets includes the energy and chemical consumption (insecticides and cleaners)

The table below (Tab. 64) summarizes the inputs and outputs considered for these two processing steps.

Tab. 64: Inputs and outputs for the peanut processing

	Peanut, in shell, dried, at plant			
		Amount	**Unit**	**Reference**
Inputs	Peanut, in shell	0.42	kg	Center for Agricultural and Rural Sustainability, 2012.
	Electricity	6.77	Wh	Center for Agricultural and Rural Sustainability, 2012.
	Diesel, manufacture and combustion	0.65	g	Center for Agricultural and Rural Sustainability, 2012.
	Natural gas, manufacture and combustion	0.0391	MJ	Center for Agricultural and Rural Sustainability, 2012.
	Propane, manufacture and combustion	0.0706	MJ	Center for Agricultural and Rural Sustainability, 2012.
Output	Peanut, in shell, dried	0.4	kg	Center for Agricultural and Rural Sustainability, 2012.
	Peanut, shelled, dried, at plant			
		Amount	**Unit**	**Reference**
Inputs	Peanut, in shell, dried	0.5	kg	Center for Agricultural and Rural Sustainability, 2012.
	Electricity	13.6	Wh	Center for Agricultural and Rural Sustainability, 2012.
	Diesel, manufacture and combustion	0.26	g	Center for Agricultural and Rural Sustainability, 2012.
	Petrol, manufacture and combustion	0.06	g	Center for Agricultural and Rural Sustainability, 2012.
	Propane, manufacture and combustion	0.00139	MJ	Center for Agricultural and Rural Sustainability, 2012.
	Cleaner, sodium hypochlorite	3.65E-6	kg	Center for Agricultural and Rural Sustainability, 2012.
	Cleaner, sodium hydroxide	2.57E-8	kg	Center for Agricultural and Rural Sustainability, 2012.
	Insecticides	9.64E-6	kg	Center for Agricultural and Rural Sustainability, 2012.
Output	Peanut, shelled, dried	0.41	kg	Center for Agricultural and Rural Sustainability, 2012.
	Peanut, shelled, dried, bleached, at plant			

		Amount	Unit	Reference
Inputs	Peanut, shelled, dried	0.43	kg	Center for Agricultural and Rural Sustainability, 2012.
	Electricity	78.5	Wh	Center for Agricultural and Rural Sustainability, 2012.
	Diesel, manufacture and combustion	3.28	g	Center for Agricultural and Rural Sustainability, 2012.
	Natural gas, manufacture and combustion	0.146	MJ	Center for Agricultural and Rural Sustainability, 2012.
	Cleaner, sodium hypochlorite	0.11	g	Center for Agricultural and Rural Sustainability, 2012.
	Insecticides	2.84E-5	g	Center for Agricultural and Rural Sustainability, 2012.
Outputs	Peanut, shelled, dried, bleached	0.41	kg	Center for Agricultural and Rural Sustainability, 2012.

Peanut, shelled, dried, bleached, roasted, at plant

		Amount	Unit	Reference
Inputs	Peanut, shelled, dried, bleached	0.42	kg	Center for Agricultural and Rural Sustainability, 2012.
	Electricity	75.6	Wh	Center for Agricultural and Rural Sustainability, 2012.
	Diesel, manufacture and combustion	3.15	g	Center for Agricultural and Rural Sustainability, 2012.
	Natural gas, manufacture and combustion	0.591	MJ	Center for Agricultural and Rural Sustainability, 2012.
	Cleaner, sodium hypochlorite	0.11	g	Center for Agricultural and Rural Sustainability, 2012.
	Insecticides	2.73E-5	g	Center for Agricultural and Rural Sustainability, 2012.
Outputs	Peanut, shelled, dried, bleached, roasted	0.41	kg	Center for Agricultural and Rural Sustainability, 2012.

Data source:

- Center for Agricultural and Rural Sustainability, 2012. National Scan-leve Life Cycle Assessment for Production of US Peanut Butter. Technical Report 3Q-2012-01. University of Arkansas, Division of Agriculture, Research and extension. Consulted in August 2019 on https://cars.uark.edu/resources-reports/Peanut_Report.pdf

5.25.3 Almond nuts

Almond nuts in shell and hull are transported to a shelling and hulling facility in proximity to the farm, where they are mechanically shelled. The process results in 3 co-products: almond kernels, shells and hulls. According to Kendall et al. (2015), almond shells are considered to be used 50% as animal bedding material and 50% as biomass-based energy, and almond hulls are used as animal feed.

Based on the calculated price of the co-products on the market, an economic allocation performed by Kendall et al., (2015) results in impacts allocated as:

- Almond kernels, from shelling and hulling, at plant (WFLDB)/GLO U: 94%
- Almond hulls, from shelling and hulling, at plant (WFLDB)/GLO U: 5%
- Almond shells, from shelling and hulling, at plant (WFLDB)/GLO U: 1%

This partitioning is applied to describe the co-product allocation. The input and output data are presented in the following table in detail.

Tab. 65: Almond kernels production inputs and outputs

Almond kernels, from shelling and hulling, at plant (WFLDB)/GLO U

	Material/Process	Amount	Unit	Reference
Inputs	Almond in shell	3.16	kg	Kendall et al. (2015)
	Transport by lorry (from farm to shelling and hulling facility)	30	km	Kendall et al. (2015)
	Electricity	0.55	MJ	Kendall et al. (2015)
	Propane	0.023	MJ	Kendall et al. (2015)
	Diesel	0.011	MJ	Kendall et al. (2015)
	Gasoline	0.0086	MJ	Kendall et al. (2015)
Outputs	Almond waste	0.28	kg	calculated
	Almond hulls	1.46	kg	Kendall et al. (2015)
	Almond shells	0.42	kg	Kendall et al. (2015)
	Almond kernels	1	kg	Kendall et al. (2015)

5.25.4 Shea nut and butter (crude)

Shea nuts in Burkina Faso are harvested in their huskss with the pulp around. The pulp is then taken off manually and they are shelled through boiling, before they are dried, within the village of harvesting (Bockel et al. 2020). The process results in three co-products: pulp, husk and kernel. No information was found on the economic valorisation of the pulp or husk (although the pulp appears to be eaten locally in the village), so 100% allocation is given to the kernel. The energy used for boiling comes from the burning of wood harvested locally, causing land degradation (Bockel et al. 2020).

The inputs and outputs are presented in the table below in detail.

Tab. 66: Shea kernel production inputs and outputs

Shea kernel (nut), at farm (WFLDB)/BF U

	Material/Process	Amount	Unit	Reference
Inputs	Shea fruit	1	kg	Bockel et al (2020)
	Wood	2.15	kg	Bockel et al (2020)
Outputs	Shea kernel	0.24	kg	Mbaiguinam et al. (2007)
	Shea pulp	0.69	kg	Mbaiguinam et al. (2007)
	Shea husk	0.07	kg	Mbaiguinam et al. (2007)

Shea butter manufacturing (crude) is assessed for two different manufacturing techniques:

- Traditional, in the village of harvesting in Burkina Faso
- Industrial, in European facilities

The traditional manufacturing is done manually in the village of harvesting, using only a wood burning stove, with wood locally harvested (Bockel et al. 2020) resulting in land degradation as well. The extraction rate considered is 40% (Bockel et al. 2020). There is no refining. A small amount of electricity and diesel is used for packaging, transport and storage by intermediaries. The inputs and outputs are presented in the table below in detail.

Tab. 67: Shea butter traditional production inputs and outputs

Shea butter, crude, traditional processing, at storage facility (WFLDB)/BF U

	Material/Process	Amount	Unit	Reference
Inputs	Shea kernel	2.5	kg	Bockel et al. (2020)
	Electricity	0.245	kWh	Bockel et al. (2020)
	Diesel	1.15	MJ	Bockel et al. (2020)
	Wood	3.6	kg	Bockel et al. (2020)
	Packaging film	0.075	kg	Bockel et al. (2020)
	Paper packaging	0.05	kg	Bockel et al. (2020)
	Jute bags	0.036	kg	Bockel et al. (2020)
Outputs	Shea butter	1	kg	Bockel et al. (2020)
	Shea meal	1.5	kg	Bockel et al. (2020)

For the industrial manufacturing, the kernels are sent to Europe, where they are processed in large factories. A mechanical extraction is considered, with no refining. Coconut oil extraction was taken as a proxy for the industrial shea butter manufacturing. The extraction rate considered is 46% (Gezahegn et al. 2016).

5.25.5 Macadamia nuts

The macadamia nuts are harvested in husk. They are then transported to a factory where the husk is removed to obtain in-shell nuts. Then the nuts in-shell ar cracked to obtain macadamia kernels. The kernels are then dried. These processing steps takes place in the farming country included in the database, i.e., South Africa.

The dataset includes the transport of macadamia nuts in husks from farm to processing facility, the electricity consumption by machinery for dehusking and cracking and the husks and shell burning. The heat required for drying the nuts in-shell is provided by the husk and shell combustion and only the electricity used for a fan to circulate the air is added for drying. According to data collected by Peterson Control Union, the fresh product has a water content of 20% and the kernel in-shell corresponds to 45% of the nut in husk. Once dried, the kernel represents 35% of the mass of the kernel and shell. The water content after drying is 1.36% (https://fdc.nal.usda.gov/fdc-app.html#/food-details/170178/nutrients). The total fresh nut in husk input for 1 kg of dried kernel is therefore 7.8 kg.

The fresh nuts are assumed to be transported by truck from farm to processing plant. An average distance of 60 km is considered based on expert judgement from Peterson Control Union.

The electricity consumption for the kernel extraction is based on the energy consumption of a machine covering the following steps: loading conveyor, grading machine, electromagnetic feeding hopper, cracking machine, shell and kernel separator (https://www.alibaba.com/product-detail/Walnut-Hazelnut-Almond-Macadamia-Nut-Breaker_1600455916753.html?spm=a2700.7724857.0.0.1aab79c8deXkAZ).

The husks and shells are burnt to bring energy to the factory according to experts from Peterson Control Union. For 1 kg of dried kernel, the amount of husk is 4.31 kg and the amount of shell is 1.9 kg. This corresponds to 3.44 kg DM husk and 1.83 kg DM shell (taking into account the water contents mentioned above). According to Abubaker 2017, the shell carbon content is 0.66 kg C/kg DM and the husk is 0.42 kg C/kg DM, i.e., 2.66 kg C for the total biomass of husk and shell per kg of dried kernel. The drying energy is provided by these husks and shells combustion and the drying process is completed by a fan of 1.1 kW, used 8 days for 8 tonnes of nuts (data provided by experts from Peterson Control Union).

Tab. 68: Macadamia nuts processing inputs and outputs

		Amount	Unit	Reference
Inputs	Macadamia nuts, in shell and husks, at farm	7.83	kg	Fresh product input: Peterson Control Union, https://fdc.nal.usda.gov/fdc-app.html#/food-details/170178/nutrients
	Truck transport	0.47	tkm	Transport from farm to processing plant: Peterson Control Union
	Electricity	0.077	kWh	Electricity for drying (fan): Peterson Control Union
	Electricity	0.028	kWh	Electricity consumption for conveyor, grading, feeding hopper, cracking, shell and kernel separator: https://www.alibaba.com/product-detail/Walnut-Hazelnut-Almond-Macadamia-Nut-Breaker_1600455916753.html?spm=a2700.7724857.0.0.1aab79c8deXkAZ
	Biomass burning, non-forest, air emissions, per kg C in biomass	2.66	kg	Husks and shells burning: Peterson Control Union, https://fdc.nal.usda.gov/fdc-app.html#/food-details/170178/nutrients, Abubaker 2017
Output	Macadamia nut kernel, dried	1	kg	

Data sources:

- Data collected by Peterson Control Union from macadamia nuts experts in South Africa
- Abubaker M, El Hawary S S, Mahrous E A, Abd El-Kader E M, 2017. Study of nutritional contents of *Macadamia integrifolia* Maiden & Betche leaves, kernel and pericarp cultivated in Egypt. International Journal of Pharmacognosy and Phytochemical Research, 9 (12).
- https://fdc.nal.usda.gov/fdc-app.html#/food-details/170178/nutrients
- Henan Sunrise Machinery Co., Walnut Hazelnut Almond Macadamia Nut Breaker Cracker Sheller Breaking Cracking Shelling Machine, Alibaba, https://www.alibaba.com/product-detail/Walnut-Hazelnut-Almond-Macadamia-Nut-Breaker_1600455916753.html?spm=a2700.7724857.0.0.1aab79c8deXkAZ, consulted June 2023

5.25.6 Brazil nuts

The brazil nuts are collected in the forests in the Amazonian region in “capsules”, containing several nuts in-shell. The wild collectors extract the nuts in-shell from the capsules directly in the forest, manually. This enables to carry a lower mass to the collection point. The nuts in-shell are then transported to a factory where the kernels are extracted from the shells. This processing step takes place in the harvesting country included in the database, i.e., Brazil.

The dataset includes the transport of brazil nuts in-shell from the collection place to processing facility, the electricity consumption by machinery for cracking and the shell burning. The heat required for drying the nuts in-shell is provided by the shell combustion and only the electricity used for a fan to circulate the air is added for drying. The kernel represents 45% of the dried kernel in shell mass (Cap et al. 2023). The moisture content of dried nut is in average 1.6% while the moisture content of fresh nuts is in average 21.6% (Kluczkovski 2020). The total fresh nut in shell for 1 kg of dried kernel is therefore 2.28 kg.

The fresh nuts in-shell are assumed to be transported by truck from collection point to processing plant. An average distance of 60 km is assumed considering the same distance as for macadamia nuts as proxy.

The electricity consumption for the kernel extraction is based on the energy consumption of a machine covering the following steps: loading conveyor, grading machine, electromagnetic feeding hopper, cracking machine, shell and kernel separator (https://www.alibaba.com/product-detail/Walnut-Hazelnut-Almond-Macadamia-Nut-Breaker_1600455916753.html?spm=a2700.7724857.0.0.1aab79c8deXkAZ). This machine is suitable for many different nuts and is assumed to be applicable for brazil nuts too.

The shells are assumed to be burnt to bring energy to the factory as for the macadamia nuts. For 1 kg of dried kernel, the amount of shell is 0.82 kg 45% of the dried kernel in shell corresponds to the shell, Cap et al. 2023). The shell dry matter content being 1.6% (Kuczkovski 2020), and the carbon content of the shell being 55.5% (Barroncas Gomes 2022), the amount of biomass burnt in kg C is 0.45 kg per kg of dried kernel. The drying energy is provided by these shells combustion and the drying process is completed by a fan of 1.1 kW, used 8 days for 8 tonnes of nuts (assuming the same data as for macadamia nuts which is based on experts from Peterson Control Union).

Tab. 69: Brazil nuts processing inputs and outputs

		Amount	Unit	Reference
Inputs	Brazil nuts, in shell, at collection place	2.28	kg	Cap et al. 2023, Kuczkovski 2020
	Truck transport	0.137	tkm	Assumption
	Electricity	0.06	kWh	Electricity for drying (fan): Peterson Control Union
	Electricity	0.018	kWh	Electricity consumption for conveyor, grading, feeding hopper, cracking, shell and kernel separator: https://www.alibaba.com/product-detail/Walnut-Hazelnut-Almond-Macadamia-Nut-Breaker_1600455916753.html?spm=a2700.7724857.0.0.1aab79c8deXkAZ
	Biomass burning, non-forest, air emissions, per kg C in biomass	0.45	kg	Cap et al. 2023, Kuczkovski 2020, Barroncas Gomes 2020
Output	Brazil nut kernel, dried	1	kg	

Data sources:

- Data collected by Peterson Control Union from macadamia nuts experts in South Africa
- Barronca Gomes I, da Silva Ferreira M, Meireles Quieroz G, Coutrim dos Santos L A, 2022. Use of Brasil nut residues for globular cacti cultivation in the Amazon region. Revista Verde de Agroecologia e Desenvolvimento Sustentavel, 17 (3).
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- Kluczkovski, A., Silva, A., Barroncas, J., Lima, J., Pereira, H., Mariosa, P., & Vinhote, M. L. (2020). Drying in Brazil Nut Processing as Tool for Prevention of Contamination by Aflatoxins. J. of Agricultural Studies, 8, 70-81. https://doi.org/10.5296/jas.v8i4.17387

6 Food preparation and storage

6.1 Home cooking

WFLDB provides customizable data for home cooking, including energy use, appliances and cookware. Baking and microwaving use time (min) as a reference flow, with the power of microwaving being adaptable as a parameter.

The following home cooking ways are modelled:

- Baking in electric oven, in high and low temperatures (220°C and 80°C), made of two phases:
  - the preheating phase, compulsory because includes the infrastructure,
  - the cooking phase.
- Microwaving
- Frying
- Boiling
- Steaming

For boiling, frying and steaming, stoves with different power supplies (electricity, gas or LPG) are considered.

When using SimaPro software, main parameters such as temperature, cooking time and volume of water (for boiling) can be customized.

Data sources:

- Bio Intelligence Service (2011), Preparatory Studies for Ecodesign Requirements of EuPs (III), Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers
- Milà i Canals L, Muñoz I, Hospido A, Plassmann K, McLaren SJ, Edwards-Jones G, Hounsome B. (2008) Life Cycle Assessment (LCA) of Domestic vs. Imported Vegetables. Case studies on broccoli, salad crops and green beans. CES Working Papers 01/08
- Sonesson,U., Janestad, H., Raaholt B. (2003) Energy for Preparation and Storing of Food - Models for calculation of energy use for cooking and cold storage in households. 709 2003, 1-56. Gothenburg, Sweden, SIK. SIK-Rapport

6.2 Food storage

WFLDB provides data for refrigerated food storage at retail and at consumer home. The following datasets are provided:

- Storage, in open freezer, at retail (WFLDB)/RER U
- Storage, in closed freezer, at retail (WFLDB)/RER U
- Storage, in open refrigerator, at retail (WFLDB)/RER U
- Storage, in closed refrigerator, at retail (WFLDB)/RER U
- Storage, in freezer, at home (WFLDB)/RER U
- Storage, in refrigerator, at home (WFLDB)/RER U

The reference flow is 1 l*day (litre-day) or 1 m3y (cubic meter-year). Conversion factor between l*day and m3y is 0.0000027397 m3y/l*day.

Data sources:

- IPCC (2004) IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System-Part 4: Refrigeration. www.ipcc.ch/pdf/special-reports/sroc/sroc04.pdf

7 Limitations

This section describes the limitations for specific datasets. They should be kept in mind when using and interpreting results obtained using these datasets. All limitations enable also to identify potential future improvement to be implemented.

- For cured vanilla, the deforestation impact potentially related to the wood used for the processing is not taken into account
- For some dairy products, it has been identified that the losses might be too high. This will be investigated in future release of the database.
- For meat and its co-products at slaughterhouse, the European prices are considered for the allocation for all regions while variations could potentially happen depending on the region.

The limitations specific to general modelling method are described in the methodological guidelines report.

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