

2026

Agri-footprint 8 Methodology Report

Part 2: Description of Data

Mérieux NutriSciences | Blonk

Agri-footprint

About us

Agri-footprint is a high-quality, comprehensive life cycle inventory (LCI) database focused on the agriculture and food sector. It covers data on agricultural products: food, feed, and agricultural intermediate products. Since its conception in 2014, Agri-footprint is widely accepted by the feed industry, food industry, LCA community, scientific community, and governmental institutions. Agri-footprint 8 has been critically reviewed by Agroscope, see review statement for more information.

Mérieux NutriSciences | Blonk is a leading international expert in food system sustainability, inspiring and enabling the agri-food sector to give shape to sustainability. Our purpose is to create a sustainable and healthy planet for current and future generations. We support organizations in understanding their environmental impact in the agri-food value chain by offering advice and developing

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List of abbreviations

- **a.i.**: Active Ingredient - The chemical component in a pesticide formulation responsible for its biological activity against target pests.
- **ADG**: Average Daily Gain - The rate of weight gain per animal over a specific period (expressed in kg/day) in livestock systems.
- **AGDM**: Above Ground Dry Matter - The dry mass of plant material above the soil surface used to determine yield and residue fractions.
- **ANFO**: Ammonium Nitrate Fuel Oil.
- **AP**: Ammonium Phosphate.
- **ARMS**: Agricultural Resource Management Survey - Primary source of information on production practices and economics conducted by the USDA.
- **AusLCI**: Australian Life Cycle Inventory Database - An Australian national initiative providing life cycle inventory data for various industry sectors, including agriculture.
- **BWT**: Ballast Weight Tonnage - The weight of water taken on by a vessel to maintain stability when not fully loaded.
- **CAN**: Calcium Ammonium Nitrate.
- **CDFA**: California Department of Food and Agriculture - State agency providing agricultural statistics, including dairy system metrics used in US models.
- **CEFS**: European Association of Sugar Producers (*Comité Européen des Fabricants de Sucre*) - Trade association representing sugar manufacturers across Europe.
- **CF**: Cropping Frequency - A metric calculating how many crop harvests take place on a single physical hectare of cropland within a year.
- **CH_4**: Methane.
- **CIS**: Commonwealth of Independent States - Regional trade classification covering post-Soviet countries.
- **CO**: Carbon Monoxide.
- **CO_2:** Carbon Dioxide.
- **COD**: Chemical Oxygen Demand.
- **CP**: Crude Protein - An estimate of total protein content in animal feed based on measured nitrogen content.
- **CSO**: Central Statistics Office - The national statistical institute of Ireland, providing agricultural and livestock data.
- **DAP**: Diammonium Phosphate.
- **DM**: Dry Matter.
- **DMI**: Dry Matter Intake.
- **DWT**: Dead Weight Tonnage.
- **EDA**: European Dairy Association - Industry group representing dairy processors, involved in establishing milk footprint parameters.
- **EF**: Environmental Footprint.
- **EIA**: Energy Information Administration - US agency providing energy pricing and fuel data used to quantify farm utility usage.
- **EMEP/EEA**: European Monitoring and Evaluation Programme / European Environment Agency - Technical emission inventory guidelines used to calculate non-CO_2 atmospheric emissions.
- **EPA**: Environmental Protection Agency - US governmental body providing national inventory reports, manure emission factors, and state-level data.
- **ERS**: Economic Research Service - USDA agency conducting economic research and publishing data on crop management practices.
- **EU**: European Union.

- **FAO**: Food and Agriculture Organization - United Nations agency that provides global agricultural, yield, trade, and forestry statistics.
- **FAOSTAT**: Food and Agriculture Organization Corporate Statistical Database - Primary online statistical database managed by the FAO.
- **FCR**: Feed Conversion Ratio.
- **FEDIOL**: Federation of the European Vegetable Oil and Proteinmeal Industry - Industry association representing European oilseed crushing and refining facilities.
- **FEFAC**: European Feed Manufacturers' Federation - Association representing European commercial compound feed producers.
- **FI**: Fallow Land Index - An adjustment factor accounting for rest periods allocated to temporary crop cultivation cycles.
- **FPCM**: Fat and Protein Corrected Milk - Standardized milk output measurement normalized for fat and protein concentrations.
- **GE**: Gross Energy - The total gross heat of combustion released when a feed or biomass unit is completely oxidized.
- **GHG**: Greenhouse Gas.
- **GIS**: Geographic Information System - Spatial data frameworks used to map georeferenced land use, water footprint, and fertilizer dose models.
- **GWT**: Gross Weight - Total mass of a freight train, including cargo load and rail wagons.
- **H/I/F**: Herbicides / Insecticides / Fungicides - The three primary supergroups of active chemical pesticides evaluated in cultivation models.
- **ha**: Hectare.
- **HCl**: Hydrochloric Acid.
- **HNO_3**: Nitric Acid.
- **H_3PO_4**: Phosphoric Acid.
- **H_2SO_4**: Sulfuric Acid.
- **ICBF**: Irish Cattle Breeding Federation - Organization supplying herd demographic and calving metrics for Irish livestock systems.
- **IFA**: International Fertilizer Association - Global organization publishing regional chemical fertilizer production and consumption statistics.
- **IFPRI**: International Food Policy Research Institute - Global institute providing spatial water management data across rice ecosystem models.
- **IPCC**: Intergovernmental Panel on Climate Change - UN body whose guidelines serve as the baseline methodology for calculating agricultural direct and indirect greenhouse gas emissions.
- **IPPU**: Industrial Processes and Product Use - Sector classification under IPCC rules covering industrial chemical production emissions.
- **IRRI**: International Rice Research Institute - Global research body providing processing parameters for rice milling and parboiling.
- **ISO**: International Organization for Standardization - International standards body publishing environmental management frameworks (e.g., ISO 14040/44 for LCA, ISO 14046 for water footprinting).
- **JRC**: Joint Research Centre - European Commission science service providing rules for data quality ratings in environmental databases.
- **K**: Potassium.
- **KCl**: Potassium Chloride.
- **km**: kilometer.
- **K_2O**: Potassium Oxide.
- **LCW**: Load Capacity Wagon - The maximum allowable payload weight per individual railway freight wagon.

- **LDT**: Light Displacement Tonnage - The baseline empty weight of an ocean vessel without fuel, cargo, water, or passengers.
- **LF**: Load Factor - The percentage of a transport vehicle's maximum carrying capacity that is actively utilized during transit.
- **LHV**: Lower Heating Value - Net heat generated by combusting a fuel unit, excluding latent heat of water vapor condensation.
- **LIC**: Livestock Improvement Corporation - New Zealand dairy farmer co-operative providing national herd performance metrics.
- **LMN**: Landbouwmonitoringnetwerk - Flemish agricultural monitoring network supplying farm economic statistics.
- **LTO**: Landing/Take-off - The operational flight phase of air cargo transport covering taxi, take-off, climb-out, and landing procedures.
- **LU**: Livestock Unit - A standardized reference unit used to aggregate different categories and ages of farm animals.
- **LUC**: Land Use Change - Direct conversion of land from one category to another (e.g., forest to cropland), releasing biogenic emissions.
- **MAP**: Monoammonium Phosphate.
- **MAPA**: Ministerio de Agricultura, Pesca y Alimentación - Spanish Ministry of Agriculture supplying national livestock feeding and manure data.
- **MAPSPAM**: Spatial Production Allocation Model - High-resolution GIS framework providing crop-specific harvested area and cropping frequency statistics.
- **MJ**: Megajoule.
- **N**: Nitrogen.
- **NASS**: National Agricultural Statistics Service - Statistical branch of the USDA supplying crop production, acreage, and chemical use statistics.
- **NE**: Net Energy - Energy available to animals for maintenance, growth, lactation, and gestation after digestive losses.
- **NH_3**: Ammonia.
- **NIR**: National Inventory Report - Annual national document submitting GHG inventory estimates under UNFCCC obligations.
- **NMVOC**: Non-Methane Volatile Organic Compounds.
- **NO**: Nitric Oxide.
- **NO_2**: Nitrogen Dioxide.
- **NO_3^-**: Nitrate.
- **NO_x:** Nitrogen Oxides.
- **NPK**: Nitrogen, Phosphorus, and Potassium.
- **N_2O:** Nitrous Oxide - Potent greenhouse gas emitted directly and indirectly from nitrogen additions to managed soils and manure systems.
- **P**: Phosphorus.
- **PAS**: Publicly Available Specification - Standardized assessment methodology (e.g., PAS 2050-1) used for calculating direct greenhouse gas emissions from land use change.
- **PDV**: Product board Animal Feed (*Productschap Diervoeder*) - Former Dutch organization that commissioned compound feed LCI studies.
- **PEF**: Product Environmental Footprint - Standardized European harmonized methodology for calculating the environmental impact of goods and services.
- **PEFCR**: Product Environmental Footprint Category Rules - Specific rules detailing how to conduct PEF studies for dedicated sector categories (such as animal feed or dairy).
- **PK:** Phosphorus and Potassium.
- **PM:** Particulate Matter.
- **$PM_{2.5}$ / PM_{10}:** Particulate Matter (sub-2.5 and sub-10 micrometers).

- **P_2O_5**: Phosphorus Pentoxide.
- **TCW**: TEU Capacity per Wagon - The maximum number of standard container units an individual flatbed rail wagon can transport.
- **TEU**: Twenty-foot Equivalent Unit - Standardized ocean container unit metric used to express transport volume capacity.
- **tkm**: Ton-kilometer.
- **TSP**: Total Suspended Particles - Air quality metric quantifying total suspended dust particles.
- **UNFCCC**: United Nations Framework Convention on Climate Change - International treaty body collecting national greenhouse gas inventory emissions data.
- **USDA**: United States Department of Agriculture: Federal executive department supplying comprehensive agricultural production statistics.
- **WW**: Weight of Wagon - The unladen tare weight of an empty freight rail wagon

Table of contents

1. Introduction 1
2. What's new? 3
   2.1 Agri-footprint 8 3
   2.2 Table of Changes 4
   2.3 US-states and Australian-LCI branded dataset 5
3. Cultivation of Crops 6
   3.1 Introduction and reader's guide 6
   3.2 Collected activity data 10
      3.2.1 Yield 10
      3.2.2 Water use 11
      3.2.3 Land Use Change 12
      3.2.4 Land occupation 14
      3.2.5 Nitrogen from manure 16
      3.2.6 Inorganic fertilizer application rates 17
      3.2.7 Capital goods 18
      3.2.8 Lime 19
      3.2.9 Seed input 19
      3.2.10 Transport requirements 20
      3.2.11 Pesticide input and emissions 20
      3.2.12 Energy input 21
   3.3 US-state level and Australian LCI 21
      3.3.1 US-State level dataset 21
      3.3.2 Australian LCI 21
   3.4 Collected activity data for roughages 22
   3.5 Modelled emissions 25
      3.5.1 Nitrous oxide (N_2O) emissions 25
      3.5.2 Ammonia (NH_3) and nitrate (NO_3^-) emissions – tier 1 28
      3.5.3 Carbon dioxide (CO_2) emissions 29
      3.5.4 IPCC tier 1 emissions factors and constants 30
      3.5.5 Nitric Oxide (NO) emissions 30
      3.5.6 Ammonia (NH_3) emissions – tier 2 31
      3.5.7 Phosphorus emissions 31
      3.5.8 Heavy metal emissions 31
      3.5.9 Emissions from drained peat soils 35
      3.5.10 Regionalized emissions and resources 37

3.5.11 Specific emissions 38
4. Processing of crops at post-harvest 40
4.1 Deshelling/dehusking 41
4.2 Drying of crops 41
4.3 Cooling of crops 42
5. Market mix of commodities 43
5.1 Market mix of raw materials 43
5.2 Market mix of processed materials 45
5.3 Transportation requirements for market mixes 46
5.3.1 Data collection 46
5.4 Production mix of raw materials 46
5.5 Group Totals Production 47
6. Processing of crops and animal products into feed and food ingredients 48
6.1 Introduction and reader's guide 48
6.1.1 Waste in processing 51
6.1.2 Water use in processing 51
6.1.3 Energy use in processing 52
6.1.4 Auxiliary material/other ingredients in processing 52
6.2 Animal products 53
6.2.1 Meat co-products 53
6.2.2 Dairy products 53
6.2.3 Wild caught fish products 53
6.2.4 Fish co-products 54
6.2.5 Fish degutting 55
6.2.6 Fish economic, mass and energy allocation 56
6.3 Cereal Products 56
6.3.1 Wet milling (maize, wheat) 56
6.3.2 Dry milling (maize, wheat, rye, oat) 57
6.3.3 Dry milling (rice) 58
6.4 Oilseed products 59
6.4.1 Crushing 60
6.4.2 Oil refining 63
6.5 Pulse products 65
6.5.1 Pulse protein-concentrates 66
6.5.2 Pulse protein isolates 68
6.6 Roots & tuber products 69
6.7 Sugar products 69

6.7.1 Sugar from sugar beet 69
6.7.2 Sugar from sugar cane 70
6.8 Fruits and vegetables products 70
7. Animal Farm Systems 71
7.1 Dairy Farm Systems 71
7.1.1 Limitations Dairy System 81
7.2 Beef System - Ireland 81
7.2.1 Limitations Beef System 83
7.3 Beef Systems – Rest of European countries 83
7.3.1 Data Sources and Methodological Approach 83
7.3.2 Herd Dynamics and Outputs 83
7.3.3 Feed Regimes and Nutrition 84
7.3.4 Manure Management and Housing 88
7.3.5 Allocation Parameters 88
7.3.6 Farm Utilities, Water, and Bedding 88
7.3.7 Emissions 89
7.3.8 Limitations Beef System 89
7.4 Pig system 90
7.4.1 Limitations Pig System 95
7.5 Poultry system 95
7.5.1 Laying hens system 95
7.5.2 Broilers system 99
7.5.3 Limitations Poultry System 103
7.6 Slaughterhouse 104
8. Background processes 106
8.1 Adjustment in water processes 106
8.2 Transport processes 106
8.2.1 Road 106
8.2.2 Water 108
8.2.3 Rail 111
8.2.4 Air 112
8.3 Fertilizers production 115
8.3.1 P&K mining 121
8.4 Fertilizers market mix 124
8.5 Amino acids from Evonik 127
9. Data quality ratings 128
10. Data limitations of Agri-footprint 8 129

11. References 130
12. List of tables and figures 139
12.1 List of tables 139
12.2 List of figures 142
Appendix I Crops Yield 144
Appendix II Crop Properties 145
Appendix III Crop classification 149
Appendix IV Seeds/Starting Material 150
Appendix V Pesticide Model 152
Appendix VI Peat Crop-Groups 158
Appendix VII List of crop and country combinations 160
Appendix VIII Water management regimes ratios 165
Appendix IX Regionalized US product footprint datasets for common feed ingredients 167
Appendix X AusLCI crop list 175
Appendix XI List of products with a coverage < 50%. 176
Appendix XII Critical Review 177

1. Introduction

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

This document contains background information on the methodology, calculation rules and data that are used for the development of the data published in the 8th release of Agri-footprint and on the website (www.agri-footprint.com). This document will be updated whenever new or updated data is included in Agri-footprint.

Agri-footprint 8 is available as a library within SimaPro, OpenLCA, HiQLCD and Earthster. Information, FAQ, logs of updates and reports are publicly available via the website (www.agri-footprint.com). Agri-footprint users can also ask questions via this website. The project team can also be contacted directly via tools@blonksustainability.nl.

While part 1 of the report outlines the choices in methodology and general principles used in the development of the database, this document (part 2) outlines the sources of data and specific modelling choices for the development of the individual datasets. Part 3 describes the main differences in impact results between the current and previous Agri-footprint versions.

The agri-food supply chain is not always so straightforward; there are many loops, such as the co-products of animal slaughtering being processed into feed ingredients. Also, some supply chains omit one or more of the steps described (e.g. various crops do not have post-harvest processing or processing). To handle these complexities, this document is structured to cover the main groups of life cycle inventories in Agri-footprint. It follows a standard agricultural supply chain (Figure 1):

- Crop Cultivations (Section 3),
- Post-harvesting of cultivated crops (Section 4),
- Market mixes of crops including transport (Section 5),
- Crops and animal processing products into food and feed (Section 6),
- Animal systems, including feed compound processing and slaughtering (Section 7),
- Background processes (Section 8).

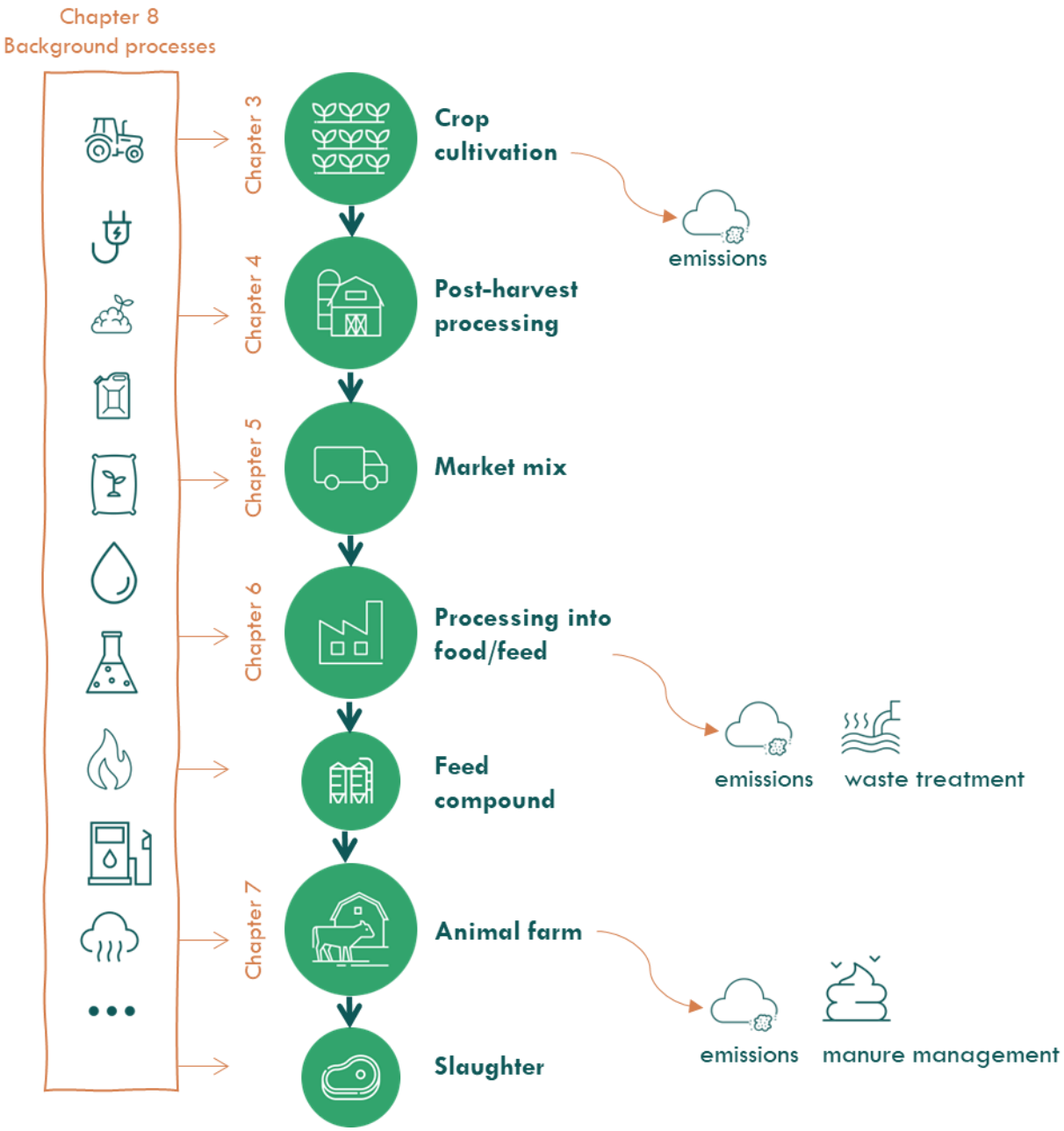


Figure 1: General agri-food supply chain representative of most Agri-footprint life-cycle stages. Indicated are also the chapters of reference for the data description.

2. What's new?

Table 2-1 Number of processes included in Agri-footprint (AFP) by version

	AFP 1	AFP 2	AFP 3	AFP 4	AFP 5	AFP 6	AFP 7	AFP8
LCIs	1,079	1,683	2,550	2,918	3,757	4,859	4,830	10,617

2.1 Agri-footprint 8

- Update of the scope of Agri-footprint: historically Agri-footprint focusses mainly on the feed production chain, but with Agri-footprint 8, (more) products for human consumption are introduced. Starting with fruit and vegetable cultivation datasets, but also more feed datasets and animal systems. The scope of Agri-footprint has increased from 4,830 (version 7) to 10,617 datasets (version 8).
- Data updates for cultivation:
  a. Crop yields from FAOstat and crop properties (section 3.2.1),
  b. Land Use Change (LUC) emissions (section 3.2.3),
  c. Manure data (section 3.2.5),
  d. Seed input from FAOstat + other sources (section 3.2.9),
  e. Pesticide data (section 3.2.11).
  f. Energy input (section 3.2.12),
  g. Peat data (section 3.4.9),
- Methodological updates for cultivation:
  a. NPK synthetic fertilizer data from NPK-GRIDS (section 3.2.6).
  b. Green and blue water footprint data (3.2.2).
  c. Land occupation (section 3.2.4),
  d. Emissions from drained peat soil (section 3.4.9).
  e. Methane emissions in rice cultivations (section 3.4.11.1).
  f. The "frac wet" factor for indirect laughing gas emissions (section 3.5.1),
- Update on production and trade statistics:
  a. Update of market mixes (section 5.1)
  b. Production mixes of raw materials (section 5.4)
- Update of the animal systems
  a. Update from IPCC 2006 to IPCC 2019 alignment (chapter 7).
  b. Beef systems included in new countries (section 7.3).
  c. Economical, Mass and Energy allocation factors updated (section 7.3.5).
- Update background data:
  a. ecoinvent background data to version 3.12 (chapter 8).
  b. Phosphor & potash mining updates (section 8.3.1)
- Bug fixes:
  a. Maize silage production is now produced from maize forage that is packed and fermented during the silage process.
  b. For sugar beet molasses, the heat and energy created is now an output, and not a negative input.
- Externally reviewed:

  A critical review of Agri-footprint 8 was performed by the Life Cycle Assessment (LCA) Research Group at Agroscope, the Swiss federal center of excellence for agricultural research. The complete critical review document can be found in the Appendix XII.

2.2 Table of Changes

Table 2-2: Table of changes between Agri-footprint 7 and 8.

Phase & chapter in methodology		Same data and modelling as Agri-footprint 7[1]	New in Agri-footprint 8		
			Updates in methodology	Updated data	Expansions
Cultivation	3	Capital goods (3.2.7) Lime (3.2.8) Transport requirements and emissions (3.2.10)	Water use now includes capillarity rise (3.2.2). NPK application rates- new data collection source (3.2.6). Seed input use- new literature sources (3.2.9). Emissions from drained peat soils (3.4.9). Frac wet for indirect N_2O emissions (3.5.1)	Yields and crop properties (3.2.1). Land Use Change (3.2.4) Manure application (3.2.5) Inorganic fertilizer (3.2.6) Seed input (3.2.9) Pesticide inputs (3.2.11) Water use (3.2.2) Energy input (3.2.12)	Fruit & vegetables.
Post-harvest	4	Deshelling/dehusking activity data (4.1) Country specific drying process (4.2)			
Market mixes	5	Transport (5.3) Regionalized fertilizer market mixes (8.4)		Market mix data as derived from FAO trade data (5.1)	Production mixes of raw materials (5.4).
Processing	6	Slaughterhouse and meat processing (6.1.2) Processing of: • Cereal products (6.3) • Pulse products (6.5) • Roots and tuber		Lucerne, Maize and Grass silage production.	

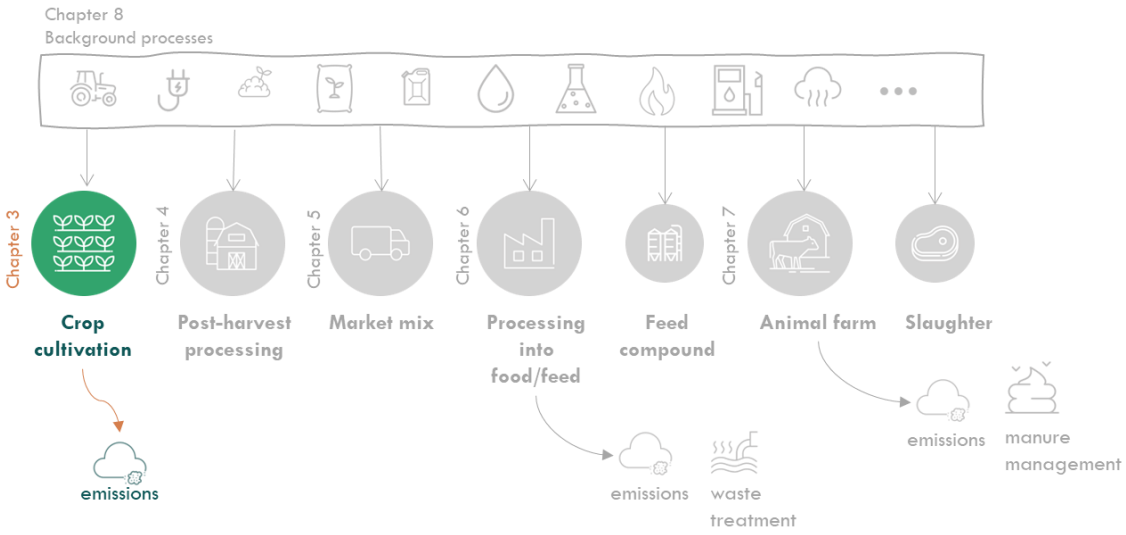
[1] Please note that even while no changes are reported in this column, the impact for a product from these processes can still change from Agri-footprint 7 to Agri-footprint 8. For example, when activity data for processing soybeans into a feed ingredient such as soybean meal (chapter 6) have not changed, but the activity data for cultivation (chapter 3) of the ingoing material soybean have changed, there will still be a difference in the soybean meal LCI for Agri-footprint 7 vs Agri-footprint 8.

		products (6.6) Sugar products (6.7) Price data for economic allocation (6.4)			
Animal production systems	7		Slaughterhouse (7.5) All animal systems (7)		New countries beef systems included.
Background data	8	Transport (8.2) Fertilizer production (8.3)	P & K mining update	Ecoinvent background data update to version 3.12.	

2.3 US-states and Australian-LCI branded dataset

For Agri-footprint 8, two new branded datasets at state/province for cultivation stage are included. Each one of them includes primary data and other sources as specific modelling characteristics, representing crops at subnational levels coverage. The list of the combinations for the US-state level dataset is described in Appendix IX, and the Australian Life Cycle Inventory Database in Appendix X.

3. Cultivation of Crops



3.1 Introduction and reader's guide

Data on crop cultivation is collected on a country basis and based on publicly available sources. Data has been updated to the period 2019 - 2023 data during the development of Agri-footprint 8 since most public data is available for these years. All modelled cultivations represent the national average within the respective country. The functional unit of the Life cycle Inventory (LCI) is one hectare of harvested area, unless something else is specified. Due to the lack of data, no distinction can be made between organic or conventional cultivation. Furthermore, crop cultivation modelling in Agri-footprint complies with European Product Environmental Footprint (PEF) guidelines. For the crop cultivation model in Agri-footprint, the following outputs, inputs, and resources are considered:

- Crop yield (kg crop product / ha cultivated)
  - Including co-production and allocation properties: price, dry matter (fresh product), gross energy content
- Water use: for irrigation and rainwater (m^3/ha/yr)
- Land occupation (ha/yr)
- Land transformations (ha/yr)
- Animal manure inputs (type and application rate kg N / ha cultivated)
- Fertilizer inputs (various types for NPK) (kg/ha)
- Capital good usage (ha/yr)
- Lime input (kg/ha)
- Start material input (kg/ha)
- Transport requirements for all of inputs (km)
- Pesticide inputs (kg/ha)
- Energy inputs (type and quantity / ha cultivated)

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

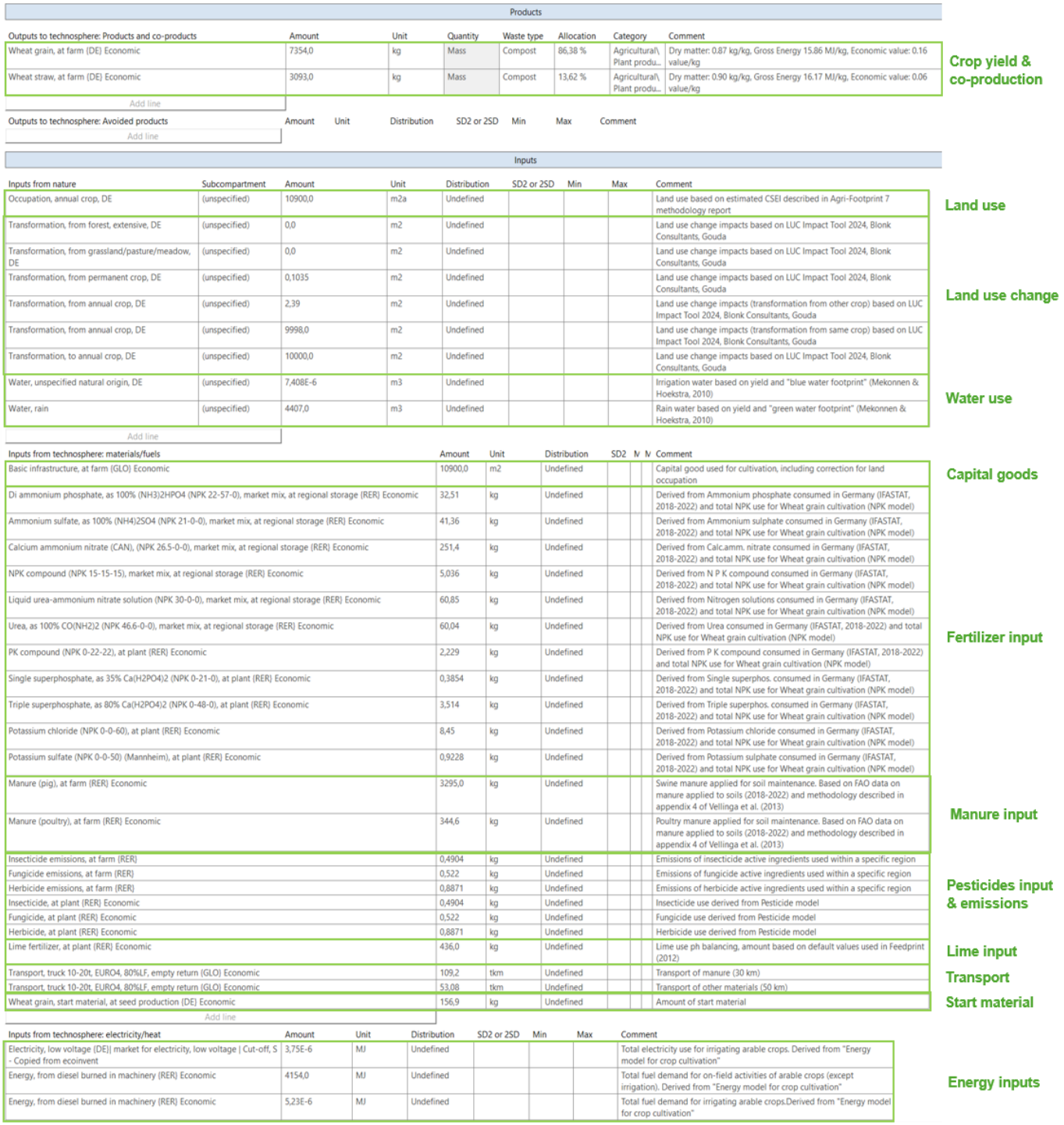
- Nitrous oxide emissions
- Ammonia emissions

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

All crop cultivation processes that have been modelled have a similar structure, an example of the crop cultivation process card in SimaPro is shown the in Figure 2 (Products and Inputs), and in Figure 3 (Emissions) below.

Data on crop cultivation is a combination of:

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



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Waste type	Allocation	Category	Comment
Wheat grain, at farm {DE} Economic	7354,0	kg	Mass	Compost	86,38 %	Agricultural\ Plant produ...	Dry matter: 0.87 kg/kg, Gross Energy 15.86 MJ/kg, Economic value: 0.16 value/kg
Wheat straw, at farm {DE} Economic	3093,0	kg	Mass	Compost	13,62 %	Agricultural\ Plant produ...	Dry matter: 0.90 kg/kg, Gross Energy 16.17 MJ/kg, Economic value: 0.06 value/kg

Add line

Crop yield & co-production

Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add line

Inputs

Inputs from nature	Subcompartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Occupation, annual crop, DE	(unspecified)	10900,0	m2a	Undefined				Land use based on estimated CSEI described in Agri-Footprint 7 methodology report
Transformation, from forest, extensive, DE	(unspecified)	0,0	m2	Undefined				Land use change impacts based on LUC Impact Tool 2024, Blonk Consultants, Gouda
Transformation, from grassland/pasture/meadow, DE	(unspecified)	0,0	m2	Undefined				Land use change impacts based on LUC Impact Tool 2024, Blonk Consultants, Gouda
Transformation, from permanent crop, DE	(unspecified)	0,1035	m2	Undefined				Land use change impacts based on LUC Impact Tool 2024, Blonk Consultants, Gouda
Transformation, from annual crop, DE	(unspecified)	2,39	m2	Undefined				Land use change impacts (transformation from other crop) based on LUC Impact Tool 2024, Blonk Consultants, Gouda
Transformation, from annual crop, DE	(unspecified)	9998,0	m2	Undefined				Land use change impacts (transformation from same crop) based on LUC Impact Tool 2024, Blonk Consultants, Gouda
Transformation, to annual crop, DE	(unspecified)	10000,0	m2	Undefined				Land use change impacts based on LUC Impact Tool 2024, Blonk Consultants, Gouda
Water, unspecified natural origin, DE	(unspecified)	7,408E-6	m3	Undefined				Irrigation water based on yield and "blue water footprint" (Mekonnen & Hoekstra, 2010)
Water, rain	(unspecified)	4407,0	m3	Undefined				Rain water based on yield and "green water footprint" (Mekonnen & Hoekstra, 2010)

Add line

Land use

Land use change

Water use

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2	N	N	Comment
Basic infrastructure, at farm {GLO} Economic	10900,0	m2	Undefined				Capital good used for cultivation, including correction for land occupation
Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage {RER} Economic	32,51	kg	Undefined				Derived from Ammonium phosphate consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage {RER} Economic	41,36	kg	Undefined				Derived from Ammonium sulphate consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage {RER} Economic	251,4	kg	Undefined				Derived from Calc.amm. nitrate consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
NPK compound (NPK 15-15-15), market mix, at regional storage {RER} Economic	5,036	kg	Undefined				Derived from N P K compound consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage {RER} Economic	60,85	kg	Undefined				Derived from Nitrogen solutions consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage {RER} Economic	60,04	kg	Undefined				Derived from Urea consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
PK compound (NPK 0-22-22), at plant {RER} Economic	2,229	kg	Undefined				Derived from P K compound consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Single superphosphate, as 35% Ca(H2PO4)2 (NPK 0-21-0), at plant {RER} Economic	0,3854	kg	Undefined				Derived from Single superphos. consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at plant {RER} Economic	3,514	kg	Undefined				Derived from Triple superphos. consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Potassium chloride (NPK 0-0-60), at plant {RER} Economic	8,45	kg	Undefined				Derived from Potassium chloride consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Potassium sulfate (NPK 0-0-50) (Mannheim), at plant {RER} Economic	0,9228	kg	Undefined				Derived from Potassium sulphate consumed in Germany (IFASTAT, 2018-2022) and total NPK use for Wheat grain cultivation (NPK model)
Manure (pig), at farm {RER} Economic	3295,0	kg	Undefined				Swine manure applied for soil maintenance. Based on FAO data on manure applied to soils (2018-2022) and methodology described in appendix 4 of Vellinga et al. (2013)
Manure (poultry), at farm {RER} Economic	344,6	kg	Undefined				Poultry manure applied for soil maintenance. Based on FAO data on manure applied to soils (2018-2022) and methodology described in appendix 4 of Vellinga et al. (2013)
Insecticide emissions, at farm {RER}	0,4904	kg	Undefined				Emissions of insecticide active ingredients used within a specific region
Fungicide emissions, at farm {RER}	0,522	kg	Undefined				Emissions of fungicide active ingredients used within a specific region
Herbicide emissions, at farm {RER}	0,8871	kg	Undefined				Emissions of herbicide active ingredients used within a specific region
Insecticide, at plant {RER} Economic	0,4904	kg	Undefined				Insecticide use derived from Pesticide model
Fungicide, at plant {RER} Economic	0,522	kg	Undefined				Fungicide use derived from Pesticide model
Herbicide, at plant {RER} Economic	0,8871	kg	Undefined				Herbicide use derived from Pesticide model
Lime fertilizer, at plant {RER} Economic	436,0	kg	Undefined				Lime use ph balancing, amount based on default values used in Feedprint (2012)
Transport, truck 10-20t, EURO4, 80%LF, empty return {GLO} Economic	109,2	tkm	Undefined				Transport of manure (30 km)
Transport, truck 10-20t, EURO4, 80%LF, empty return {GLO} Economic	53,08	tkm	Undefined				Transport of other materials (50 km)
Wheat grain, start material, at seed production {DE} Economic	156,9	kg	Undefined				Amount of start material

Add line

Capital goods

Fertilizer input

Manure input

Pesticides input & emissions

Lime input

Transport

Start material

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Electricity, low voltage {DE}| market for electricity, low voltage | Cut-off, S - Copied from ecoinvent	3,75E-6	MJ	Undefined				Total electricity use for irrigating arable crops. Derived from "Energy model for crop cultivation"
Energy, from diesel burned in machinery {RER} Economic	4154,0	MJ	Undefined				Total fuel demand for on-field activities of arable crops (except irrigation). Derived from "Energy model for crop cultivation"
Energy, from diesel burned in machinery {RER} Economic	5,23E-6	MJ	Undefined				Total fuel demand for irrigating arable crops.Derived from "Energy model for crop cultivation"

Energy inputs

Figure 2: Product, Co-product and Inputs for an Agri-footprint 8 cultivation LCI of Wheat cultivation in Germany as shown in SimaPro.

Outputs

Emissions to air	Subcompartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Nitrogen monoxide, DE	(unspecified)	1,377	kg	Undefined				Manure emissions based on NO emission based on default emission factors (EMEP/EEA, 2016)	
Dinitrogen monoxide	(unspecified)	0,5409	kg	Undefined				Direct Manure emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	Manure emissions
Dinitrogen monoxide	(unspecified)	0,2564	kg	Undefined				Indirect Manure emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Ammonia, DE	(unspecified)	8,777	kg	Undefined				Manure emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Carbon dioxide, land transformation	(unspecified)	1,678	kg	Undefined				Land use change impacts based on LUC Impact Tool 2024, Blonk Consultants, Gouda	Land use emissions
Carbon dioxide, fossil	(unspecified)	60,36	kg	Undefined				Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Dinitrogen monoxide	(unspecified)	2,034	kg	Undefined				Direct Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Dinitrogen monoxide	(unspecified)	0,7608	kg	Undefined				Indirect Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	Fertilizer emissions
Ammonia, DE	(unspecified)	7,836	kg	Undefined				Fertilizer emissions based on tier 2 ammonia emissions described in Air Pollutant Emission Guidebook (EMEP/EEA, 2016)	
Nitrogen monoxide, DE	(unspecified)	5,178	kg	Undefined				Fertilizer emissions based on NO emission based on default emission factors (EMEP/EEA, 2016)	
Carbon dioxide, peat oxidation	(unspecified)	772,0	kg	Undefined				Emissions from peat oxidation based on Peat emissions based on average peat land emissions (FAOSTAT, 2021) and crop/country specific correction factors from GIS data (Monfreda, et al. 2008)	
Methane, peat oxidation	(unspecified)	0,0	kg	Undefined				Emissions from peat oxidation based on Peat emissions based on average peat land emissions (FAOSTAT, 2021) and crop/country specific correction factors from GIS data (Monfreda, et al. 2008)	Peat emissions
Dinitrogen monoxide, peat oxidation	(unspecified)	0,531	kg	Undefined				Emissions from peat oxidation based on Peat emissions based on average peat land emissions (FAOSTAT, 2021) and crop/country specific correction factors from GIS data (Monfreda, et al. 2008)	
Dinitrogen monoxide	(unspecified)	1,02	kg	Undefined				Direct Crop residues emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Dinitrogen monoxide	(unspecified)	0,2693	kg	Undefined				Indirect Crop residues emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	Crop residues emissions
Carbon dioxide, fossil	(unspecified)	191,8	kg	Undefined				Lime and dolomite emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	Lime emissions

Add line

Emissions to water	Subcompartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Nitrate, DE	(unspecified)	29,73	kg	Undefined				Manure emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Phosphorus, DE	(unspecified)	0,9141	kg	Undefined				Manure emissions based on freshwater eutrophication potentials for phosphorus (Huijbregts et at, 2016)	Manure emissions
Cadmium (II)	(unspecified)	3,83E-5	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Chromium, ion	(unspecified)	0,01902	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Copper, ion	(unspecified)	0,00355	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Lead (II)	(unspecified)	0,0003017	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	Heavy metals emissions
Mercury (II)	(unspecified)	8,054E-7	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Nickel (II)	(unspecified)	0,0	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Zinc (II)	(unspecified)	0,02773	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Nitrate, DE	(unspecified)	111,8	kg	Undefined				Fertilizer emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	
Phosphorus, DE	(unspecified)	0,9402	kg	Undefined				Fertilizer emissions based on freshwater eutrophication potentials for phosphorus (Huijbregts et at, 2016)	Fertilizer emissions
Nitrate, DE	(unspecified)	56,08	kg	Undefined				Crop residues emissions based on tier 1 calculations described in Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)	Crop residues emissions

Add line

Emissions to soil	Subcompartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Cadmium (II)	agricultural	0,00218	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Chromium, ion	agricultural	0,0	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Copper, ion	agricultural	0,1361	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Lead (II)	agricultural	0,01824	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	Heavy metals emissions
Mercury (II)	agricultural	4,133E-5	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Nickel (II)	agricultural	0,01222	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	
Zinc (II)	agricultural	0,2951	kg	Undefined				Heavy metals emissions based on heavy metals emissions described in Nemecek & Schnetzer (2012)	

Figure 3: Emissions for an Agri-footprint 8 cultivation LCI of Wheat cultivation in Germany as shown in SimaPro.

3.2 Collected activity data

3.2.1 Yield

Yield of almost all crops in Agri-footprint is based on yields per harvested area reported in FAO Statistics (FAO, 2026a), using a five-year average from 2019 till 2023. The functional unit of the LCI is one hectare of harvested area, unless something else is specified. The standard deviation is calculated from these five datapoints. When it is required, data from different periods of years are used.

The quality of the reported data by FAO may vary due to the complexities of the collection process. Consequently, different classifications are applied based on the data source, providing a label that reflects the reliability of the values utilized. The labels applied are:

- FAO (Official figure): Data provided directly by governments through official national channels (such as ministries of agriculture or national statistical offices). This is the most reliable data.
- FAO (External figure): Data collected from recognized external authorities or international organizations (like the World Bank or Eurostat) when official country reports are unavailable.
- FAO (Estimated value): Data calculated by FAO experts using statistical methodologies, algorithms, and historical trends to fill in missing or inconsistent data gaps.

For some crops not included in FAO Statistics, yield data is obtained from alternative sources, for some of these cases, the standard deviation could not be calculated due to insufficient data. This applies to grass, maize forage, lucerne and other country/crop combinations (12.2Appendix I).

3.2.1.1 Crop properties

The dry matter content (kg/kg) and the Gross Energy (MJ/kg) crop properties were updated for Agri-footprint 8 based on fresh crop matter; this data is necessary to calculate the emissions of the processes. Due to this update, some changes may be expected on the emissions for Economic, Mass and Energy allocation. Detailed values can be found in 12.2Appendix II.

The dry matter content of the crop is used to replace the dry matter value provided by the IPCC on the equation for the total amount of crop residues generated after the harvest process (3.5.1). This is because the IPCC defaults do not match well between the modelled crops that are available in Agri-footprint, especially for roughage systems. For example IPCC provides a default of 90% dry matter content for Alfalfa, Non-legume hay, N-fixing forages, Non-fixing forages, Perennial Grasses and Grass-Clover Mixtures, whereas in Agri-footprint these crops have a lower dry matter content when harvested and would only be available in dried form after further processing/post-harvesting.

3.2.1.2 Co-production

In Agri-footprint 8, the yield of the co-product is based on the fraction of “Above ground dry matter” (AGDM) or crop residues that can be harvested. The default harvesting factors for crop (groups) are based on “sustainable removal rates” or “practically removable fractions”. Since harvesting of the co-product varies considerably around the world, largely depending on demand for these roughages locally, it was chosen to use half of the maximum removal rates from literature. This resulted in the following removal fractions used in Agri-footprint 8:

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

3.2.1.3 Properties of the co-products

The dry matter content and gross energy data content of the products are based on specific sources for each crop. Economic value of the main and co-products is based on market trading prices for feed commodities in the United Kingdom[2,3].

Table 3-1: Prices used for economic allocation of specific crop groups since Agri-footprint 6.3.

Product (group)	Price (£/kg)	Co-product	Price (£/kg)	Comment
Cereal grain	0.16	Cereal straw/stover	0.06	Cereals based on wheat prices
Pulse	0.23	Pulse straw	0.03	Pulses based on pea prices
Linseed Rapeseed Soybeans	0.3	Straw	0.05	All three crops based on rapeseed prices

3.2.2 Water use

3.2.2.1 Irrigation water

Agri-footprint 8 updates blue water footprint data by transitioning from Mekonnen & Hoekstra (2010) to the updated statistics provided by Mialyk et al. (2024).

The “Blue Water footprint” refers to the volume of surface and groundwater (capillary rise) consumed as a result of crop production. In Agri-footprint 7 and previous versions, the amount of irrigation water for all cultivation processes was based on the ‘blue water footprint’ assessment of Mekonnen & Hoekstra (2010). Mialyk et al. (2024) offers a wider range of crop-country combinations including data from 1990-2019 period and provides the data for capillary rise.

The model used considers grid-based dynamic water balances, daily soil water balances, crop water requirements, actual water use and actual yields. The water footprint of crops has been published per country in m^3/ton of product. Combined with crop yields (FAO 2019-2023) the total consumed blue water footprint is calculated in m^3/ha. The estimation of irrigation water is based on the CROPWAT approach (Allen et al., 1998) using the following equation:

$$Blue\ water\ consumption\ (m^3/ha) = Blue\ water\ footprint\ (m^3/ton) * Yield\ crop\ (ton/ha)$$

Equation 3-1

Blue water use is reported in Agri-footprint 8 as “Water, unspecified natural origin” (sub-compartment ‘in water’), with a specific country suffix, making the elementary flow region specific (e.g. “Water, unspecified natural origin, FR” – in water). Hereby the user is enabled to perform water stress-related impact studies.

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

In cases where the data does not exist in Mialyk et al. (2024), data from Mekonnen & Hoekstra (2010) is used as a fallback.

3.2.2.2 Capillary Rise

Agri-footprint 8 adds capillary rise to the water consumption of crops. Capillary rise is the process where soil moisture is drawn upward against gravity toward the root zone. This is included as groundwater consumption in addition to irrigation. Since groundwater use is part of the blue water footprint, the inclusion of capillary rise means that there are 2 sources of the blue water use for crops in Agri-footprint 8. This is also included for rainfed crops, resulting in a higher blue water footprint for crops that previously only had a green water footprint

Blue water use from capillary rise is reported in Agri-footprint as “Water, unspecified natural origin” (sub-compartment ‘in water’), with a specific country suffix, making the elementary flow region specific (e.g. “Water, unspecified natural origin, FR” – in water). Hereby the user is enabled to perform water stress-related impact studies. Capillary rise is reported similarly to the irrigation water use, but the sub-compartment “in ground” is used instead.

3.2.2.3 Rainwater

Agri-footprint 8 includes ‘green water footprints or rainwater to cultivation inventory. The same approach was used as described for irrigation water. The substance flow of rainwater (called “Water, rain” in SimaPro) is not characterized by most commonly applied characterization methods (e.g. EF Method or ReCiPe). But since it is still included in the inventory, the user can hereby adjust the method to include rainwater in their calculations in various LCA software if needed.

3.2.3 Land Use Change

Fossil CO_2 emissions resulting from direct land use change were estimated using the Direct Land Use Change Assessment Tool version 2026 that was developed alongside the PAS 2050-1 (BSI, 2012). This tool provides a predefined way of calculating greenhouse gas (GHG) emissions from land use change based on FAO statistics and IPCC calculation rules, following the PAS 2050-1 methodology. GHG emissions arise when land is transformed from one use to another. The most well-known example of this is conversion of forests to crop land. This tool can be used to calculate the emissions for a specific country-crop combination and attribute them to the cultivated crops.

The calculation has been under development continuously since the publication of the PAS 2050-1, has been reviewed by the World Resource Institute and has, as a result, earned the ‘built on GHG Protocol’ mark. Main updates for the 2026 version as implemented in Agri-footprint 8 are related to the update of FAOSTAT data to latest available statistical data, up to 2023. This tool can be used to quantify land use change emissions in conformance with the GHG Protocol standards[4]. The tool provides three basic functionalities, based on data availability of the user. All these approaches are described in the PAS 2050-1 published by BSI and are made operational in this tool using various IPCC data sources (IPCC, 2006b, 2019a).

For Agri-footprint 8, the option “calculation of an estimate of the GHG emissions from land use change for a crop grown in a given country if previous land use is not known” was used. This estimate is based on a number of reference scenarios for previous land use, combined with

[4] http://www.ghgprotocol.org/standards

data from relative crop land expansions based on FAOSTAT data. These FAO statistics then provide an estimate of the share of the current cropland (for a given crop) which is the result of land use change from forest and/or grassland to cropland. This share is calculated based on an equal amortization period of 20 years (2004-2023), as described in the PAS 2050-1. This results in three scenarios of land transformation (m^2 / ha * year): forest to (perennial or annual) cropland, grassland to (perennial or annual) cropland, and transformation between perennial and annual cropland, depending on the crop under study. The resulting GHG emissions are then the weighted average of the carbon stock changes for each of these scenarios. We use the weighted average because, in our opinion, this most accurately estimates the Land Use Change. In the development of Agri-footprint we have the principles that we want to provide consistent data across inventories, and the 'best estimate' rather than a worst-case approach, which the PAS 2050-1 advises. See Annex B of the PAS 2050-1 for an example calculation (BSI, 2012).

In case of grassland management, data gaps from FAO statistics had to be solved. Since no grassland expansion was reported in the past 20 years by FAO statistics, LUC impacts due to grassland management were not accounted for (the emissions reported are 0), except for Brazil, Paraguay and French Guyana.

FAO statistics do not report roughages crops. The roughages are divided into two categories:

- Perennial roughages: Based on the Managed grassland emissions reported by FAO (Grass (16% DM), Lucerne, Hay N fixing and non-N fixing, other forages).
- Annual roughages: These forage cereals LUC are based on the grain product type due to the similar time occupation, labor similarities (tillage and sowing), and the possibility of the grain cereals to be used as roughages. Maize forage – Maize grain, Rye forage – Rye grain, and Sorghum forage – Sorghum grain.

The carbon stock change calculations used for each are based on IPCC rules and default data for soil carbon stocks and carbon stock in grassland (IPCC 2006 and 2019). FAO statistics on land coverage of specific crops, total annual and perennial cropland and total grassland and forestland to calculate conversions (including data up to 2023) and the Forest Resource Assessment provides country-specific carbon stocks in natural forests (FAO, 2026). The basic approach is to first calculate the carbon stocks in the soil and vegetation of the old situation and then subtract these from those of the new situation, to arrive at the total carbon stock change. The assumptions for carbon stocks are dependent on country, climate & soil type. Emissions from nitrogen mineralization are related to oxidation of soil organic carbon and are included in the total emissions from land use change (IPCC 2019). A nice example of such a calculation is provided in the 'Annotated example of a land carbon stock calculation' document, which can be found at the European Commission's Biofuel site. The soil organic carbon changes and related biomass references are taken from various IPCC tables, which are documented in the direct land use change tool itself.

The calculated CO_2 emissions from LUC have been added in the database, the substance flow name is "Carbon dioxide, land transformation". Note that land transformations from forest, grassland, arable crops and perennial crops are also included for each cultivation (in m^2 per harvested hectare).

The different land use transformation categories reported by the LUC 2026, a short descriptive comment is present in the LCI; to produce Soybeans in Brazil (BR) in Agri-footprint 8, the categories descriptions are mentioned in

Table 3-2:

Table 3-2: Land use categories description

Categories	Description	Amount m^2
Transformation, from forest, extensive, BR	Indicates the total m^2 transformed to produce soybeans in Brazil that were previously a forest.	199.138
Transformation, from grassland/pasture/meadow, BR	Indicates the total m^2 transformed to produce soybeans in Brazil that were previously grassland/pasture/meadow.	61.162
Transformation, from permanent crop, BR	Indicates the total m^2 transformed to produce soybeans in Brazil that were previously a permanent crop.	7.859
Transformation, from annual crop, BR (other crop)	Indicates the total m^2 transformed to produce soybeans in Brazil that were previously another annual crop.	31.945
Transformation, from annual crop, BR (same crop)	Indicates the total m^2 transformed to produce soybeans in Brazil, that were previously soybeans in Brazil.	9699.895
Transformation, to annual crop, BR	Indicates the total m^2 transformed to produce 1 ha of soybeans in Brazil.	10000
Methane, land transformation	Total Methane emissions generated (kg) due to the land transformation for the soybeans production in Brazil, calculated by the LUC Impact Tool (2026).	0
Dinitrogen monoxide, land transformation	Total Dinitrogen monoxide emissions generated (kg) due to the land transformation for the soybeans production in Brazil, calculated by the LUC Impact Tool (2026).	0.216
Carbon dioxide, land transformation	Total Carbon dioxide emissions generated (kg) due to the land transformation for the soybeans production in Brazil, calculated by the LUC Impact Tool (2026).	9224.682

3.2.4 Land occupation

3.2.4.1 Distributing the land occupation of agriculture over multiple cropping systems

With increasing global food demand, land use efficiency gains are part of the solution to stop deforestation and other natural land conversions for agricultural land. Multiple cropping is a practice where a plot of land is subsequently planted with varying crops and harvested multiple times in a year. This practice is increasingly applied worldwide, contributing to increasing harvested areas without demanding additional agricultural land. Sometimes multiple crops are grown at the same time on a field; called intercropping. The most common goal of intercropping is to increase the yield of a cropland, for example by growing crops next to the trees in an orchard.

Within Life Cycle Assessment (LCA) studies it is often required to report the emissions emerging from LUC, such as the clearance of forests to cultivate crops, separately. However, multiple cropping activities are not always considered in agricultural LCA databases. The assumption that the occupation duration for a harvest of temporary crops is always 1 year, led to an overestimation of both the LUC emissions and the land occupation impact, especially in countries where multiple cropping practices are ubiquitous. Multiple cropping primarily occurs in tropical and subtropical regions where there is sufficiently long rainy season or suitable irrigation to cultivate two or three crops sequentially within a single agricultural year.

The definition of how much land is occupied by a crop per harvested hectare per year at national scale is not a simple task, this requires a consistent methodology to be applied to all the cases in the database. In Agri-footprint 7 the Crop System Efficiency Index (CSEI) was developed to fulfil this task, due to a dynamic limitation and a lack of crop specificity, a new method was developed with the assistant of Geographic Information Systems, this new method is Land Occupation. A change in land occupation affects the land use change

transformation and GHG, land occupation, lime emissions, peat emissions and the capital goods.For example, a crop rotation system of planting soybeans during the spring-summer seasons, harvesting the crops in late summer or early fall, and planting wheat in the same field after and harvesting this in spring-summer seasons (Figure 4).

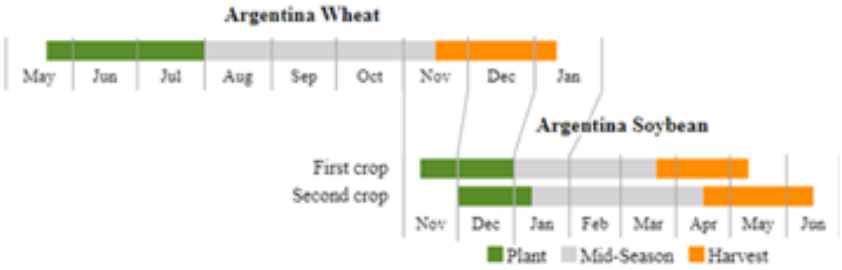


Figure 4: Multiple cropping in Argentina (2 crops/ha/yr) (Argentina Soybean Area, Yield and Production).

There are two components that define the actual land occupation to harvest one hectare (the functional unit) in Agri-footprint. Land occupation is calculated with the equation below.

$$Land\ occupation\ (ha * year) = \frac{Fallow\ land\ index\ (-)}{Cropping\ frequency\ (year^{-1})} * 1ha$$

Equation 3-2

Where:

Fallow land index: Accounts for the rest periods allocated to temporary cropland cycles.

Cropping frequency (year $^{-1}$): Measures how often a physical area is harvested per year.

3.2.4.2 Calculating the cropping frequency

Cropping frequency is defined as how many harvests are taking place on a physical hectare of cropland in one year. For example, if in one year on one hectare of land, soybeans are grown followed by wheat, the cropping frequency of that hectare is 2. Which would result in a cropping frequency of 2 (year^{-1}) for both the soybean and the wheat. Intercropping also results in a higher cropping frequency. For example, if in between one hectare of an olive orchard, some legumes are also grown, there are also 2 hectares of harvest within one physical hectare, leading to a cropping frequency of 2.

$$Cropping\ frequency\ (year^{-1}) = \frac{Harvested\ area\ (ha/year)}{Physical\ cropland\ area\ (ha)}$$

Equation 3-3

To calculate the cropping frequency of a crop in a country, the Spatial Production Allocation Model (MAPSPAM) was used (Cao et al., 2026). MAPSPAM reports both the physical area and the harvested area of crops within a country. Because the crops are reported individually, it is now possible to create a cropping frequency that is crop & country specific. MAPSPAM indicates it is sometimes limited to information about multi-cropping. For crops where multi-cropping is not clearly reported, it often simply falls back to a cropping frequency of 1.

3.2.4.3 Calculating the fallow land index

As fallow land is associated with crop rotation and multiple cropping, it is allocated to all temporary croplands. This is expressed in the fallow land index (FI):

$$Fallow\ land\ index\ (-) = 1 + \frac{Fallow\ land\ area\ (ha)}{Temporary\ cropland\ area\ (ha)}$$

Equation 3-4

For Agri-footprint 8, the values used to calculate the fallow land index were derived from land use data from 2021-2023, as reported by the FAO (FAO, 2026e). Currently only one value for fallow land is reported per country, meaning that this average value represents the fallow land index for all temporary crops in that country. In some countries, high amounts of fallow land are reported in FAO. Based on expert judgement, a maximum limit on the Fallow land index was established on 1.33. This would represent a system where one hectare of land is harvested for three years and then put to rest for one year. For permanent crops the Fallow Land index is 1, as that hectare is never put to rest. To determine if a crop is temporary or permanent the FAO definitions are used:

Temporary crops: This category belongs to all crops with a productive period < 5 years. In this category we can find all annual, and a few perennial crops. According to the FAOSTAT definition, the perennial crops included in this category are ***asparagus***, ***strawberries***, ***pineapples***, ***bananas*** and ***sugar cane*** (see also 12.2Appendix III).

Permanent crops: This category belongs to all crops with a productive period > 5 years. All *remaining* perennial crops are in this category (see also 12.2Appendix III).

An example on how fallow land and cropping frequency influence parameters in the database is shown in Table 3-3.

Table 3-3: Fallow land and cropping frequency example

Crop/Country	Soybeans/AR	Soybeans/JP	Soybeans/ES
Occupation, annual crop (m^2a)	9569.04	10000	13259
Cropping frequency	1.111	1	1
Fallow land index	1.063	1	1.326
Basic infrastructure (m^2)	9569.04	10000	13259
Lime fertilizer applied (kg/ha)	382.76	400	530.2

3.2.5 Nitrogen from manure

The methodology for calculating manure application rates follows Vellinga et al. (2013a), where rates are determined by dividing the total manure nitrogen applied by the total harvested area in each country. Although actual application practices vary considerably by crop, region, and season, this model applies a national average for all crops. This aggregation is justified by the lack of granular regional data and by the multi-year residual nutrient benefits manure provides across crop rotations.

Data on manure applied to soils and harvested area are sourced from FAOSTAT (FAO, 2026a, 2026b) using a five-year country average (2019–2023). FAOSTAT distinguishes between two primary management pathways across livestock categories: manure applied to soils (mechanically spread) and manure left on pasture (direct deposition by grazing animals). For Agri-footprint 8, manure nitrogen is allocated based on animal type and cropping system:

- **Arable Crops:** Only swine and poultry manure categorized as *applied to soils* is allocated to harvested arable cropland. High-intensity production systems—specifically orchards, poly-tunnels, and greenhouses—are assumed to receive no manure. Equation 3-5 defines the country-specific application rate (kg N/ha) for poultry and swine manure across arable land:

$$Manure\ applied\ (kg/ha) = \frac{Total\ manure\ applied\ (kg)}{Total\ harvested\ area\ (ha)}$$

Equation 3-5

- **Roughage and Grassland:** Bovine manure is allocated exclusively to forage and pasture systems, differentiated by management type:
    a. Manure applied to soils (annual roughages): Represents mechanically spread slurry and solid manure. The application rate is calculated by dividing total bovine manure applied to soils by the combined area of temporary fallow and permanent meadows/pastures (FAO, 2026a).
    b. Manure left on pasture (perennial roughages): Represents direct animal excretion during grazing. The deposition rate is calculated by dividing total bovine manure left on pasture by the total grassland area, defined as the sum of temporary fallow, temporary meadows, and permanent meadows/pastures (FAO, 2026a).

Finally, using manure nitrogen concentrations from Wageningen UR (2012), the nitrogen doses are converted into fresh manure quantities ("as is") and inventoried in the Life Cycle Inventory (LCI).

3.2.6 Inorganic fertilizer application rates

The NPK application rate represents the amount of Nitrogen (N), Phosphorus (P_2O_5), and Potassium (K_2O) applied to a crop per unit of area (kg/ha). This information is obtained from 2 different sources:

NPKGRIDS: GIS-based NPK data, a georeferenced map of fertilizer doses distributed all around the world, with 173 different crops represented. Built up from 8 different sources (Nguyen et al., 2024). To get the usage of NPK per country, fertilizer use was calculated by using a weighted average of the harvested areas as provided by CROPGRIDS (Tang et al., 2024). The weighted average was only considered in areas where both data of CROPGRIDS and NPKGRIDS were present. To determine country shapes, the FAO Global Administrative Unit Layers (Franceschini et al., 2025) was used.

As a quality criterion, if CROPGRIDS did not report NPK doses for that specific crop/country combination, or provided less than 100 hectares of harvested area, the NPK doses will be retrieved from literature.

Literature NPK data: NPK fertilizer doses obtained directly from literature sources like scientific studies, production manuals, industrial recommendations, and other sources. Each source used is mentioned in the specific process description.

3.2.6.1 Specific fertilizer types

To match the total N, P and K application rates, to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.), 5-year average (2019-2023) data on regional fertilizer consumption rates from IFA statistics were used (IFA, 2026).

3.2.6.2 Biological N fixation: Legumes

The legume crops have the potential to create a symbiosis to allow the crop to get atmospheric nitrogen fixed. This is a source of the nutrient that reduces the total N fertilizer doses required. Agri-footprint does not model the nitrogen fixation realized by legume plants, which is a limitation of the database and will be considered for future updates.

3.2.6.3 Specific fertilizer ratio use

To match these total N, P and K application rates and to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.), data on regional fertilizer consumption rates from (IFA, 2026) were used.

Some fertilizers supply multiple nutrient types (for example ammonium phosphate application supplies both N and P to agricultural soil). In IFA statistics (IFA, 2025), the share of ammonium phosphate is given as part of total N and also as part of total P supplied in a region. To avoid double counting, this dual function was taken into account.

Therefore, the following calculation approach was taken:

1. A fertilizer type is considered in isolation (e.g. only potassium supplying fertilizers, or only nitrogen). The relative shares of the specific fertilizers were calculated for a crop (e.g. if a crop A in Belgium requires 10 kg K/ha, 35% is supplied from NPK, 52% from potassium chloride and 11% from potassium sulfate). However, some fertilizers supply nutrients of different types (e.g. both N and P or N, P and K). The amounts of other nutrients supplied are subtracted from the total nutrient requirements.
2. Next, the share of the second fertilizer type is calculated, considering the amount of nutrient supplied by multi-nutrient fertilizers from the previous step. Again, other nutrients supplied are subtracted from the requirements for the last fertilizer type.
3. For the remaining nutrient, the single nutrient supplying fertilizers are used (as NPK and ammonium phosphate etc. are already considered during previous calculation steps).

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

For consistency, the approach used for Agri-footprint 8 is therefore to determine the order of N, P and K from smallest to largest for each specific crop/country combination and use that order for the calculation. E.g. for a crop requiring N:60 kg, P:20 kg, K: 30 kg, the calculation starts with calculating the shares of specific fertilizers for P then K and finally N.

3.2.7 Capital goods

The capital goods in cultivation processes are called “Basic infrastructure”, which is the same process as modelled in the PEFCR for feed (European Commission, 2018). The assumption is that 30 m^2 of roads and pavements are applied per hectare and affected by the land

occupation. Using concrete slabs, 15 cm thick, lifetime of 33.3 years (Wageningen UR, 2015)and density of 2400 kg/m^3, the total concrete input for basic infrastructure can be determined, which is 327.27 kg concrete per hectare*year, using an amortization period of 33 years.

The basic infrastructure surface is directly linked to the land occupation of that crop:

$$Basic\ infrastructure\ surface\ (m^2) = Land\ occupation\ (m^2)$$

Equation 3-6

Silo and tractors also have amortization; the silo have lifetime of 35 years and storage 260 ton of grain per year, the tractors have 14 years of lifetime, including a repair factor of 74%. Silo is used during the storage process and tractor in the energy from diesel burned in machinery. These processes use inputs from ecoinvent.

3.2.8 Lime

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

Lime is affected by the land occupation of a crop. As mentioned in chapter 3.2.4, the lime doses are based on kg/ha per year, using the following equation:

$$Lime\ (kg) = 400\ kg/ha/year * \ land\ occupation\ (ha * year)$$

Equation 3-7

3.2.9 Seed input

Seed input or start material for cultivation is based on different literature references or in FAOstat crop cultivation statistics (FAO, 2026), the values for each crop can be found in Appendix IV. Seed input in Agri-footprint is based on 5-year average data from 2019 till 2023. In Agri-footprint versions 3 and 4, seed input was based on crop country specific data, in which the seed input varied considerably among countries, due to data quality issues. In order to tackle this, it was chosen to use global average seed input for each crop as start material, based on the same data from Agri-footprint 5 onward[5]. Starting materials for orchard perennial crops and horticultural crops grown from seedlings or transplants are excluded from the inventory calculations. This is justified by the negligible environmental contribution of nursery activities when amortized over the total lifetime or the total productive volume of these systems. The nursery impacts are distributed across several decades of crop production, for annual horticultural crops raised from transplants, the resource inputs during the nursery phase are minor relative to the overall emissions during the main field cultivation phase. The inclusion of seedlings for specific crops and orchards is considered for future updates.

3.2.9.1 Yield correction for cultivation of start material

In Agri-footprint 8, the background process of seed material is a copy of the cultivation process of the same crop country combination, with the exception that the yield of the seed background process is adjusted, which is the so called “yield ratio”. In Agri-footprint 8, the yield correction factor is different per crop (type) based on data of Feedprint. In Table 3-4, some crop examples

[5] https://blonksustainability.nl/news/behind-the-scenes-seed-application-and-seed-production-in-agri-footprint

are shown. Hereby, the seed production process can be less productive in terms of yield and thereby results in higher environmental burdens compared to the main crop.

Table 3-4: Overview of assumptions in Feedprint cultivation seed production that is applied in Agri-footprint.

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

3.2.10 Transport requirements

Transport requirements are based on:

- A transportation distance of 30 km for manure.
- A transportation distance of 50 km for all other inputs (synthetic fertilizer, lime, pesticides and seeds).

Transportation requirements are added in the inventory as ton*km (tkm), using the following formula:

$$Transport\ requirement - manure\ (tkm) = 30\ km * mass\ manure\ (ton)$$

Equation 3-8

$$Transport\ requirement - other\ inputs\ (tkm) = 50\ km * mass\ other\ inputs\ (ton)$$

Equation 3-9

3.2.11 Pesticide input and emissions

There is a complex relation between the total amount of pesticides used and ecotoxicity impact caused, due to large differences between the toxicities (i.e. characterization factors) of individual substances. In order to accurately predict impacts from ecotoxicity, specific pesticides applications are needed (in kg active ingredient (a.i.) per pesticide/ha). In practice, however, this level of detail in pesticide application data is often difficult to achieve. There are only a few countries who monitor and report reliable data on the application of pesticide active ingredients per crop.
Until Agri-footprint 4, Pesticide application inventory based on a thorough literature study were included. This approach proved difficult to continue as the database grew and limited the possibility of updating the data on a yearly basis.

Since Agri-footprint 5, a more simplified approach is used. The pesticide applications per crop and country of cultivation (kg a.i./ha) were modelled for insecticides, herbicides and fungicides based on 5-year average data from 2019-2023, recent FAO statistics for total pesticide use (FAO, 2026c) and the modelling rationale explained in Appendix V. The use of statistical data allows for continuous update of this inventory simplifies the inclusion of new crop/country cultivation processes to the Agri-footprint portfolio. Moreover, following a modelling logic rather

than trying to compile the scarcely available specific pesticide application rates per country and crop, gives what we consider, the 'best estimate' of pesticide inputs per crop.
The pesticide inventory in Agri-footprint 8 is a default inventory which can be used to gain insights into the toxicity impact of biomass considering the limitations as reported in chapter 10. Primary data for pesticide data (when available) are always preferred over this inventory.

3.2.12 Energy input

Since Agri-footprint 5, the "Energy model for crop cultivation" was used to determine the energy demand (Van Paassen et al., 2018). The tool was developed in co-operation between representatives from Wageningen University and Blonk Consultants. The model has a bigger scope and uses the most recent specific indicators, such as yield, mechanization factors and irrigation, to determine the energy use at cultivation stage more accurately. Also, the energy demand for irrigation is reported separately (diesel as well as electricity demand for irrigation). Hereby, it would be possible to make more detailed contribution analysis of irrigation. For Agri-footprint 8, the same model methodology has been applied, updated with the latest statistics for tillage, yield, irrigation and manure application.

3.3 US-state level and Australian LCI

3.3.1 US-State level dataset

The state-level cultivation modelling for US is done for maize (corn), soybeans, wheat, and sorghum, capturing at least 95% of national production (91% for winter wheat due to data withholding). Activity data included were extracted from the USDA NASS Quick Stats tool for the 2018-2024 window, using specific data for yield, starting material, fertilizers, pesticides, manure application, and irrigation inputs. Datasets were built by averaging seven years of yield data and at least two years of chemical and irrigation inputs. More information about the US state data collection is described in Appendix IX. The list of crop/state combinations are in Appendix IX- Section 8. US-State level crop list.

3.3.2 Australian LCI

The agricultural data published in AusLCI (the Australian Life Cycle Inventory Database Initiative) have been developed and updated over time by a number of collaborative projects, with funding and support from various agricultural research agencies and government departments. To process the data in Agri-footprint 8, the crop-template service was used to calculate the impact of the emissions. The data provided is yield, crop properties, value, start material, irrigation, specific n-p-k fertilizers used, transport distances, fuel consumption, lime applied, fractions removed and burned and pesticides applied. Inventoried data on di ammonium phosphate was modelled as 50% mono ammonium phosphate and 50% super triple super phosphate by mass. The direct and indirect emissions on fertilizers were adjusted to the Agri-footprint calculation schema, using specific Australian emission factors for direct laughing gas emissions and specific state level data on wet climate factors. The AusLCI list of crop/state combinations are in 12.2Appendix X.

3.4 Collected activity data for roughages

Key activity data for roughages are not available in publicly available statistics like FAOstat. Therefore, for roughages like fodder beet, grass, maize forage and lucerne that are part of the Agri-footprint database, specific datapoints are collected differently. Table 3-5 shows an overview of the key activity data collected for roughages: yield (fresh yield) and synthetic mineral fertilizer use. For manure, a similar approach is used for roughages as described in section 3.2.5, with the exception that manure requirements for roughages are fulfilled by manure from bovine; the nutrients provided by manure are not counted as fertilizers in the production process. Due to a lack of information for pesticide applications, 0 kg/ha is assumed.

Table 3-5 Key activity data for roughages

Country	Roughage	Yield (kg/ha)	Source	Irrigation (m^3/ha)	N (kg N/ha)	P (kg P_2O_5/ha)	K (kg K_2O/ha)	Source synthetic fertilizer
DE	Grass	37500	(Smit, Metzger, & Ewert, 2008)	0	43.85	30.62	30.53	NPK GIS model
FR	Grass	31250	(Smit, Metzger, & Ewert, 2008)	9	22.14	34.99	34.99	NPK GIS model
IE	Grass	62500	(Smit, Metzger, & Ewert, 2008)	0	67	11	16	Pallière, C. (2011) Grass based on "Total Grassland"
IT	Grass	40000	Smit, H. J., Metzger, M. J., & Ewert, F. (2008)	64	5.75	10.55	10.47	NPK GIS model
NL	Grass	60606	(Smit, Metzger, & Ewert, 2008)	0	150	17	5	Pallière, C. (2011) Grass based on "Total Grassland"
PL	Grass	25000	(Smit, Metzger, & Ewert, 2008)	0	20.84	6.66	6.66	NPK GIS model
GB	Grass	56250	(Smit, Metzger, & Ewert, 2008)	0	54	8	11	British Survey of Fertiliser Practice Fertiliser use on farm for the 2019 crop year
US	Grass	38087	USDA, National Agricultural Statistics Service, 2017. Data for hay.	0	9.43	9.27	9.27	NPK GIS model
NZ	Grass	75000	Aden, N., Change, C., Farm, F., Barron, N., & Shannon, M. (2015). Grassland Production & Utilisation	0	140	57	24	Reviewer NZ
AU	Grass	62500	Aden, N., Change, C., Farm, F., Barron, N., & Shannon, M. (2015). Grassland Production & Utilisation (Value for NZ)	0	3	9	2	IFA (2017) Assessment of Fertilizer Use by Crop at the Global Level, Australian bureau of statistics, 2017 for total managed grassland area.
BE	Grass	37500	(Smit, Metzger, & Ewert, 2008)	0	40	35.33	50	NPK GIS model
BR	Grass	75000	Maciel, A.M. Life Cycle Assessment of Milk Production. 2019. 82p. (Ecology Master Dissertation) - Federal University of Juiz de Fora, Institute of Biological Sciences. Juiz de Fora, 2019.	0	2.93	4.12	4.08	NPK GIS model
ES	Grass	15710	Eurostat 2018-2022 data	0	18.97	45.9	45.7	NPK GIS model
DK	Grass	65000	(Smit, Metzger, & Ewert, 2008)	0	98.66	7.62	7.62	NPK GIS model
DE	Maize forage	43196	FAO 2014-2018, based on Maize	61	52.07	8.15	15.09	NPK GIS model
FR	Maize forage	41255	FAO 2014-2018, based on Maize	481	35.8	20.09	20.1	NPK GIS model
IT	Maize forage	52000	Smit, H. J., Metzger, M. J., & Ewert, F. (2008)	349	148.5	6.03	12.53	NPK GIS model
NL	Maize forage	46478	FAO 2014-2018, based on Maize	322	46.67	5.11	3.16	NPK GIS model
PL	Maize forage	28642	FAO 2014-2018, based on Maize	9.5	125	49.55	68.94	NPK GIS model

BE	Maize forage	44671	FAO 2014-2018, based on Maize	297	55	30	55	NPK GIS model
BR	Maize forage	85000	Maciel, A.M. Life Cycle Assessment of Milk Production. 2019. 82p. (Ecology Master Dissertation) - Federal University of Juiz de Fora, Institute of Biological Sciences. Juiz de Fora, 2019.	46	13.17	8.9	8.86	NPK GIS model
DK	Maize forage	46478	FAO 2014-2018, based on Maize	47.11	40.22	11.99	9.08	NPK GIS model
IT	Lucerne	27300	Eurostat 2014-2018 data	341	5.77	11.78	11.7	NPK GIS model
ES	Lucerne	37567	Eurostat 2014-2018 data	356	18.97	45.9	45.7	NPK GIS model
DK	Lucerne	49716	Eurostat 2014-2018 data	18	96	8.5	8.5	NPK GIS model
US	Lucerne	19768	USDA, National Agricultural Statistics Service, 2017.	294.91	31.89	40.38	40.2	NPK GIS model
NL	Fodder beet	80670	Fodder beet, growers guidelines 2019. in UK	1273	29.97	10.5	10.5	NPK GIS model
NL	Lucerne	27500	Phosphorus and Potassium Fertilization of Alfalfa. Sofia Lissbrant, W. Kess Berg, Jeffrey Volenec, Sylvie Brouder, Brad Joern, Suzanne Cunningham, and Keith Johnson	310	30	10.5	10.5	NPK GIS model
NZ	Maize forage	20470	New Zealand survey of maize areas and volumes.	0.03	134.1	132.9	74	NPK GIS model
US	Maize forage	8174	Corn for Silage Area Harvested, Yield, and Production – States and United States: 2018-2020. Crop Production 2020 Summary (January 2021). USDA, National Agricultural Statistics Service	265	163.7	56.91	60.73	NPK GIS model

3.5 Modelled emissions

Table 3-6 gives an overview of what emissions are considered and which methods are used to quantify the emission flow. Besides this, not all emissions are considered for the most important aspects. For instance, dinitrogen monoxide emissions are quantified for fertilizer inputs, manure inputs and crop residues, but is “not applicable” for lime inputs. Note that ammonia emissions from manure are based on the tier 1 IPCC methods, whereas for fertilizer use ammonia emissions are based on the more detailed method described in EMEP/EEA.

Table 3-6: Overview of modelled emissions, literature source and which aspects are included for the calculations

Emission	Level	Method	Fertilizer	Manure	Crop residues	Lime
(In)direct laughing gas emissions	Tier 1	IPCC (IPCC, 2019b)	Yes	Yes	Yes	-
Ammonia emissions	Tier 1		No	Yes	No	-
Nitrate emissions	Tier 1		Yes	Yes	Yes	-
Carbon dioxide emissions	Tier 1		Yes	-	-	Yes
Nitrogen oxides emissions	Tier 1	EMEP/EEA (European Environment Agency, 2016)	Yes	Yes	No	-
Ammonia emissions	Tier 2		Yes	No	No	-
Phosphorus emissions		ReCiPe (M. A. J. Huijbregts et al., 2016)	Yes	Yes	No	-
Heavy metal emissions		Nemecek & Schnetzer (Nemecek & Schnetzer, 2011)	Yes	Yes	Yes	Yes

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

- Methane emissions for rice cultivation (see also paragraph 3.5.11.1)

The beef cattle and dairy cows’ production system emissions due to the excretion of manure on pasture generated during the grazing time of the animals are not reported as part of the system direct emissions. Instead, the Agri-footprint 8 modelling approach reports these emissions as part of the background “Grass production” datasets. This cut-off approach at the beef cattle and dairy cow production system avoids double counting of emissions.

3.5.1 Nitrous oxide (N_2O) emissions

There are several pathways that result in nitrous oxide emissions, which can be divided into direct emissions (release of N_2O directly from N inputs) and indirect emissions (N_2O emissions through a more intricate mechanism). Besides nitrous oxide emissions due to N additions, there are other activities that can result in direct nitrous oxide emissions, such as the drainage of organic soils, changes in mineral soil management, and emissions from urine and dung inputs to grazed soils. The emissions due to drainage of organic soils are mentioned in section 3.5.9. The emissions due to changes in mineral soil management are calculated in section 3.2.3. The emissions from grazing of pastureland are however included in the animal system

models. The following equations and definitions are derived from IPCC methodologies on N_2O emissions from managed soils;

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

Equation 3-10 (IPCC, 2019b)

Where:

N_2O-N_{Direct} = annual direct N_2O-N emissions produced from managed soils, [kg N_2O-N]

N_2O-$N_{N\ inputs}$ = annual direct N_2O-N emissions from N inputs to managed soils, [kg N_2O-N]

N_2O-N_{OS} = annual direct N_2O-N emissions from managed organic soils, [kg N_2O-N]

N_2O-N_{PRP} = annual direct N_2O-N emissions from urine and dung inputs to grazed soils, [kg N_2O-N]

Note that the unit kg N_2O-N should be interpreted as kg nitrous oxide measured as kg nitrogen. In essence, Equation 3-11 (IPCC, 2019b) to Equation 3-16 (IPCC, 2019b)describe nitrogen balances. To obtain [kg N_2O], [kg N_2O-N] needs to be multiplied by $\left(\frac{44}{28}\right)$, to account for the mass of nitrogen (2*N, atomic mass 14) within the mass of a nitrous oxide molecule (2*N+1*O, atomic mass 16). See Table 3-7 for a list of emissions factors and constants.

The N_2O emissions from inputs are driven by four different parameters; the application rate of synthetic fertilizer, application of organic fertilizer (e.g. manure), annual release of N in soil organic matter due to land use change, and amount of crop residue left after harvest. The latter was incorporated in the aggregated emissions from land use change as described in 0.

In addition to the direct emissions, there are also indirect emission pathways, in which nitrogen in fertilizer is first converted to an intermediate compound before it is converted to N_2O (e.g. volatilization of NH_3 and NO_x which is later partly converted to N_2O). The different mechanisms are shown schematically in Figure 5.

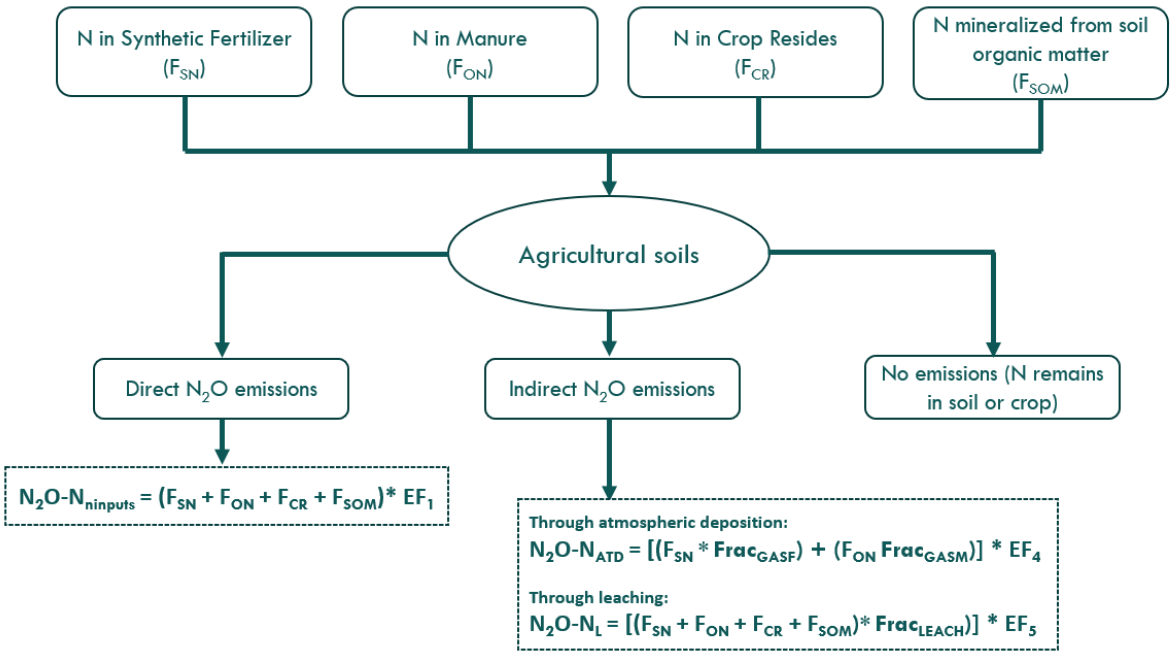


Figure 5: Nitrous oxide emission (direct and indirect) from due to different N inputs (IPCC, 2019b)

The equations listed in Figure 5 will be discussed in more detail below. First, the major contribution from direct emissions of N_2O is from N inputs:

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

Equation 3-11 (IPCC, 2019b)

Where:

F_{SN} = the amount of synthetic fertilizer N applied to soils, [kg N]

F_{ON} = the amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, [kg N]

F_{CR} = the amount of N in crop residues (above-ground and below-ground), including N-fixing crops (leguminous), and from forage/pasture renewal, returned to soils, [kg N]

F_{SOM} = the amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management, [kg N]

EF_1 = emission factor for N_2O emissions from N inputs, $[\frac{kg\ N_2O-N}{kg\ N\ input}]$

As mentioned before, the contribution of F_{SOM} is incorporated in the emissions from land use change, which are calculated elsewhere (see 0). F_{CR} is dependent on the type of crop and yield and is determined separately. The IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019b) provides guidance on how to do this using an empirical formula and data for a limited number of crops and crop types. The emission factor EF_1 in Equation 3-11 has a default value of 0.01 (i.e. 1% of mass of N from fertilizer and crop residue will be converted to N_2O); as listed in Table 3-7.

In Agri-footprint 8, the direct N_2O emissions are modelled according to the IPCC (2019b) Tier 1 approach. The uncertainty range of the EF_1 emission factor is very high (0.002 – 0.018) because climatic conditions, soil conditions and agricultural soil management activities (e.g. irrigation, drainage, tillage practices) affect direct emissions.

F_{SN} has been determined using mainly data from NPKGRIDS as described in Section 3.2.6 of this report. The contribution of F_{ON} has been determined on a country basis, as described in the methodology report of the Feedprint study (Vellinga et al., 2013a), which formed the basis of the crop cultivation models in this study, see Section 0.

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

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

Equation 3-12 (IPCC, 2019b)

Where:

$N_2O_{(ATD)}$-N = amount of N_2O–N produced from atmospheric deposition of N volatilized from managed soils, [kg N_2O–N]

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

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

$$N_2O - N_{ATD} = [(F_{SN} * Frac_{GASF}) + ((Fon + Fprp) * FracGASM)] * EF_4$$

Equation 3-13 (IPCC, 2019b)

Where:

F_{SN} = annual amount of synthetic fertilizer N applied to soils, [kg N]

F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, [kg N]

$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, $\left[\frac{kg\ N\ volatilized}{kg\ N\ applied}\right]$

$Frac_{GASM}$ = fraction of applied organic N fertilizer materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilizes as NH_3 and NO_x, $\left[\frac{kg\ N\ volatilized}{kg\ N\ applied\ or\ deposited}\right]$

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, $\left[\frac{kg\ N_2O-N}{kg\ NH_3-N+NO_x-N\ volatilized}\right]$

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, [kg N]

In Agri-footprint 8, no mixed enterprise farming systems are considered. Therefore, in the crop cultivation models, F_{PRP} was set to 0 (no urine and dung from grazing animals). However, emissions from grazing were considered in animal systems where appropriate. The default emission factor EF_4 and the default fractions are listed in Table 3-7. Equation 3-1414 shows the calculation procedure for determining N_2O emission from leaching of applied N from fertilizer (SN and ON), crop residue (CR), grazing animals (PRP) and soil organic matter (SOM).

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

Equation 3-14 (IPCC, 2019b)

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

EF_5= emission factor for N_2O emissions from N leaching and runoff, $\left[\frac{kg\ N_2O-N}{kg\ N\ leached\ and\ runoff}\right]$

$Frac_{wet}$ represents the share of wet climate within a country, data is taken from the land use change tool (Blonk Consultants, 2021). This wet component factor is introduced in Agri-footprint 8 for indirect laughing gas emissions. Hereby cultivations in dry climates benefit more from lower indirect laughing gas emissions compared to wet climate cultivations.

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

Again, the IPCC calculation rules (IPCC, 2019b) were applied to determine the ammonia and nitrate emissions. This approach of modelling ammonia volatilization was used only for emissions from manure; the ammonia volatilization from inorganic fertilizer was indeed modelled following EMEP/EEA guidelines (see chapter 3.2.6). It was assumed that all nitrogen that volatizes converts to ammonia, and that some leached nitrogen is emitted as nitrate. In essence, Equation 3-15 (IPCC, 2019b) & Equation 3-16 (IPCC, 2019b)are the same as the aforementioned equations for nitrous emissions from atmospheric deposition and leaching (Equation 3-13 (IPCC, 2019b) & Equation 3-14 (IPCC, 2019b)) but without the secondary conversion to nitrous oxide.

Ammonia (NH_3) emissions:

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

Equation 3-15 (IPCC, 2019b)

Where:

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

Nitrate (NO_3^-) emissions to water:

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

Equation 3-16 (IPCC, 2019b)

Where:

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

The IPCC includes a note "that in the Tier 1 method, for wet climates or dry climate regions where irrigation (other than drip irrigation) is used, the default $Frac_{leach}$ is 0.24. For dry climate, the default $Frac_{leach}$ is zero." $Frac_{wet}$ represents the share of wet climate within a country, data is taken from the land use change tool (Blonk Consultants, 2021).

3.5.3 Carbon dioxide (CO_2) emissions

Carbon dioxide emissions from lime, dolomite and urea containing compounds are included in the inventory. Both lime and dolomite are resources of fossil origin. Carbon dioxide emissions from urea containing compounds are included as well since: "CO_2 removal from the atmosphere during urea manufacturing is estimated in the Industrial Processes and Product Use Sector (IPPU Sector)" (IPCC, 2019b). In Agri-footprint, two urea containing compounds are present: urea (which is 100% urea) and liquid urea ammonium nitrate solution (which contains 36.6% urea).

CO_2 emissions from limestone, dolomite and urea containing compounds:

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

Equation 3-17 (IPCC, 2019b)

Where:

CO_2–C_{em} = C emissions from lime, dolomite and urea application, [kg C]

$M_{limestone}$, $M_{dolomite}$, M_{urea} = amount of calcic limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) or urea respectively, in [kg]

$EF_{limestone}$, $EF_{dolomite}$, EF_{urea} = emission factor, $\left[\frac{kg\ C}{kg\ of\ limestone, dolomite\ or\ urea}\right]$

Default emission factors are reported in Table 3-7.

3.5.4 IPCC tier 1 emissions factors and constants

Table 3-7: IPCC Tier 1 emission factors and constants.

IPCC Tier 1 Emission factors and constants [and units]	Value [IPCC 2019]
$EF_1 \left[\frac{kg\ N_2O - N}{kg\ N_{applied}}\right]$	0.01
$EF_4 \left[\frac{kg\ N_2O - N}{kg\ N_{volatized}}\right]$	0.01
$EF_5 \left[\frac{kg\ N_2O - N}{kg\ N_{leached}}\right]$	0.011
$EF_{Dolomite} \left[\frac{kg\ CO_2 - C}{kg\ Dolomite}\right]$	0.13
$EF_{Lime} \left[\frac{kg\ CO_2 - C}{kg\ lime}\right]$	0.12
$EF_{Urea} \left[\frac{kg\ CO_2 - C}{kg\ Urea}\right]$	0.2
$Frac_{GASM} \left[\frac{kg\ NH_3 - N}{kg\ N_{in\ manure\ applied}}\right]$	0.21
$Frac_{GASF} \left[\frac{kg\ NH_3 - N}{kg\ N_{in\ fertilizer\ applied}}\right]$	0.11
$Frac_{LEACH} \left[\frac{kg\ NO_3^- - N}{kg\ N_{applied}}\right]$	0.24
Conversion from kg CO_2-C to kg CO_2	$\left(\frac{44}{12}\right)$
Conversion from kg N_2O-N to kg N_2O	$\left(\frac{44}{28}\right)$
Conversion from kg NH_3-N to kg NH_3	$\left(\frac{17}{14}\right)$
Conversion from kg NO_3^--N to kg NO_3^-	$\left(\frac{62}{14}\right)$

3.5.5 Nitric Oxide (NO) emissions

Since Agri-Footprint 5, nitric oxide emissions from fertilizer and manure application are considered. Although nitric oxide is produced as an intermediate product of the nitrification and denitrification processes, no methodology has been developed in the IPCC guidelines of 2006 to quantify its emission. A default value of 0.04 kg NO_2 per kg of N fertilizer and kg N from manure applied is used since Agri-footprint 6 (European Environment Agency, 2016).

3.5.6 Ammonia (NH_3) emissions – tier 2

For ammonia emissions from inorganic fertilizers, a more detailed tier 2 approach is used based on emission factors for specific type of fertilizers described by EMEP/EEA (European Environment Agency, 2016). All eight inventoried nitrogen containing fertilizers in chapter 3.2.6 each have their own specific emission factor described in Figure 6.

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

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

Figure 6: Emission factors for ammonia emissions from fertilizers (g NH3/kg N applied) (European Environment Agency, 2016).

Due to the lack of data on the pH of soils, it is assumed that all soils around the world are "normal". Using the climate zone criteria described in the reference and average temperatures of countries around the world, each country is either classified as "cool", "temperate" or "warm". This simplification might lead to an underestimation of the emitted ammonia, since the "high pH" scenario leads to higher ammonia emissions. Including pH conditions of soils for more precise ammonia modelling will be considered for future development of Agri-footprint.

3.5.7 Phosphorus emissions

The phosphorus content of synthetic fertilizers and manure is emitted to the water. An emission factor of 0.1 per kg of phosphorus for manure and synthetic fertilizer based on default modelling of ReCiPe (M. Huijbregts et al., 2016) is applied.

3.5.8 Heavy metal emissions

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

Heavy metals are added to the soil due to application of fertilizers and manure and due to deposition. The heavy metal content of fertilizers and manure was based on literature as stated

in Table 3-8 and Table 3-9, respectively. The deposition of heavy metals is stated in Table 3-10.

Table 3-8: Heavy metal content of fertilizers

Mineral fertilizers	Unit	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Urea	mg/kg	2.796	36.301	12.116	0.047	9.739	25.583	94.598
Nitrogen solutions	mg/kg	1.800	23.370	7.800	0.030	6.270	16.470	60.900
NPK compound	mg/kg	6.840	94.005	18.195	0.060	16.755	18.405	157.230
Anhydrous ammonia	mg/kg	4.920	63.878	21.320	0.082	17.138	45.018	166.460
Ammonium nitrate	mg/kg	2.100	27.265	9.100	0.035	7.315	19.215	71.050
Calcium ammonium nitrate	mg/kg	1.658	22.656	8.883	0.036	6.975	15.877	62.940
Ammonium phosphate	mg/kg	23.835	326.648	57.305	0.193	54.929	50.268	522.890
Ammonium sulfate	mg/kg	1.260	16.359	5.460	0.021	4.389	11.529	42.630
Triple superphosphate	mg/kg	18.960	260.640	43.440	0.144	42.384	32.160	402.720
Single superphosphate	mg/kg	8.295	114.030	19.005	0.063	18.543	14.070	176.190
PK compound	mg/kg	8.712	120.736	20.966	0.066	19.976	14.916	185.944
Ground rock	mg/kg	12.640	173.760	28.960	0.096	28.256	21.440	268.480
Potassium chloride	mg/kg	0.060	3.480	2.880	0.000	1.500	0.480	3.720
Potassium sulfate	mg/kg	0.050	2.900	2.400	0.000	1.250	0.400	3.100
Lime	mg/kg	0.280	8.249	8.169	0.040	5.886	5.446	37.481

Table 3-9: Heavy metal content of manure

Manure	Unit	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Cattle	mg/kg	0.038	1.755	4.378	0.017	1.594	1.211	18.254
Pigs	mg/kg	0.060	1.230	42.059	0.007	1.621	1.260	94.674
Poultry	mg/kg	0.952	5.446	61.974	0.053	11.925	10.141	293.594

Above European values are also used for other continents because data is not available, incomplete or it is not stated if the values are ‘per kg dry matter’ or ‘per kg manure as is’. Note that ranges in heavy metal contents of animal manure are large as shown in Table 3-9. And note that the amount of copper (Cu) and zinc (Zn) in pig slurry and manure are high because additional copper and zinc is added to the feed by pig farmers for animal health reasons.

It is assumed that only pig and poultry manure are applied in cultivation of arable crops[6] because cattle systems are often closed-loop systems. The ratio pig / poultry manure is based on FAO data on the amount of available nitrogen per type of animal manure.

Table 3-10: Deposition of heavy metals (Nemecek & Schnetzer, 2012)

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

Heavy metals are removed from the soil via removal of biomass and via leaching. The heavy metal content of biomass of crops is shown in Table 3-11. Leaching heavy metals to ground water is mentioned in Table 3-12Table 3-13.

Table 3-11: Heavy metals in biomass in mg/kg "as is" (Delahaye et al., 2003)

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

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

Table 3-12 : Heavy metal leaching to groundwater (Nemecek & Schnetzer, 2012)

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

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

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

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

Equation 3-18

Where:

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

$\boldsymbol{M_{agro\ i}}$ = input due to agricultural activities (fertilizer and manure application) for heavy metal i

$\boldsymbol{M_{deposition\ i}}$ = input due to deposition for heavy metal i

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

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

Equation 3-19

Where:

$\boldsymbol{M_{leach\ i}}$ = leaching of heavy metal i to the ground and surface water

$\boldsymbol{m_{leach\ i}}$ = average amount of heavy metal emission *(*Table 3-10*)*

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

Heavy metals emissions to the soil are calculated as follows:

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

Equation 3-20

Where:

$\boldsymbol{M_{soil\ i}}$ = accumulation in the soil of heavy metal i

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

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

Equation 3-21

Where:

$\boldsymbol{A}$ = fertilizer application (kg/ha/yr)

$\boldsymbol{A_{content\ i}}$ = heavy metal content i for fertilizer applied (Table 3-8)

$\boldsymbol{B}$ = manure application (kg DM/ha/yr)

$B_{content\ i}$ = heavy metal content i for manure applied (Table 3-9)

C = deposition (Table 3-10)

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

Equation 3-22

Where:

D = yield (kg DM/ha/yr)

$D_{content\ i}$ = heavy metal content i for crop (Table 3-11)

When more heavy metals are removed from the soil via leaching and biomass than is added to the soil via fertilizers, manure and deposition, the balance can result in a negative emission. In Agri-footprint 8, negative emissions are converted to zero.

3.5.9 Emissions from drained peat soils

In Agri-footprint 8, the methodology for peat calculations has been updated. First a baseline emission per country for peat emissions was defined. Afterwards, a crop specific value was calculated by using the adjusting the baseline emission with a correction factor.

3.5.9.1 Baseline emission approach

Two major sources of peat emissions per country are being used. If available, the baseline emissions of peat are sourced from the National Inventory Reports (NIR). The reported emission values, are calculated with Equation 3-23 and Equation 3-24, with the total cropland area as documented within the same NIR. Where the NIR provided N_2O emissions for organic soils, these data served as the baseline for the country's peat-related N_2O emission estimates. The year of reference for all NIR reports is 2022.

$$NBE_{CO_2} = ((\frac{-CSOS}{12}) * 44) / TCO$$

Equation 3-23

NBE_{CO2} = NIR Base emission (kg CO_2/ha)

CSOS = Carbon stock organic soil (kg C)

TCO = Total cropland area (ha)

$$NBE_{N_2O} = NEC / TCO$$

Equation 3-24

NBE_{N2O} = NIR Base emission (kg N_2O/ha)

NEC = Total N_2O Emissions of Cropland (kg)

TCO = Total cropland area (ha)

In cases where the NIR does not provide sufficient information for a country to calculate the baseline emissions for either CO_2 or N_2O, the baseline emissions are based on the "Spatially explicit global assessment of cropland greenhouse gras emissions circa 2020" study (Cao, P. et al. 2026). This study provides peat emissions (Figure 7) for 46 different crop-groups (12.2Appendix VII). Data is sourced from the supplementary table: Source Data Figs. 1-6. Note that the NIR never reports CH_4 emissions of organic soils, therefore the organic soil CH_4 emissions are always sourced from Cao et al. (2026).

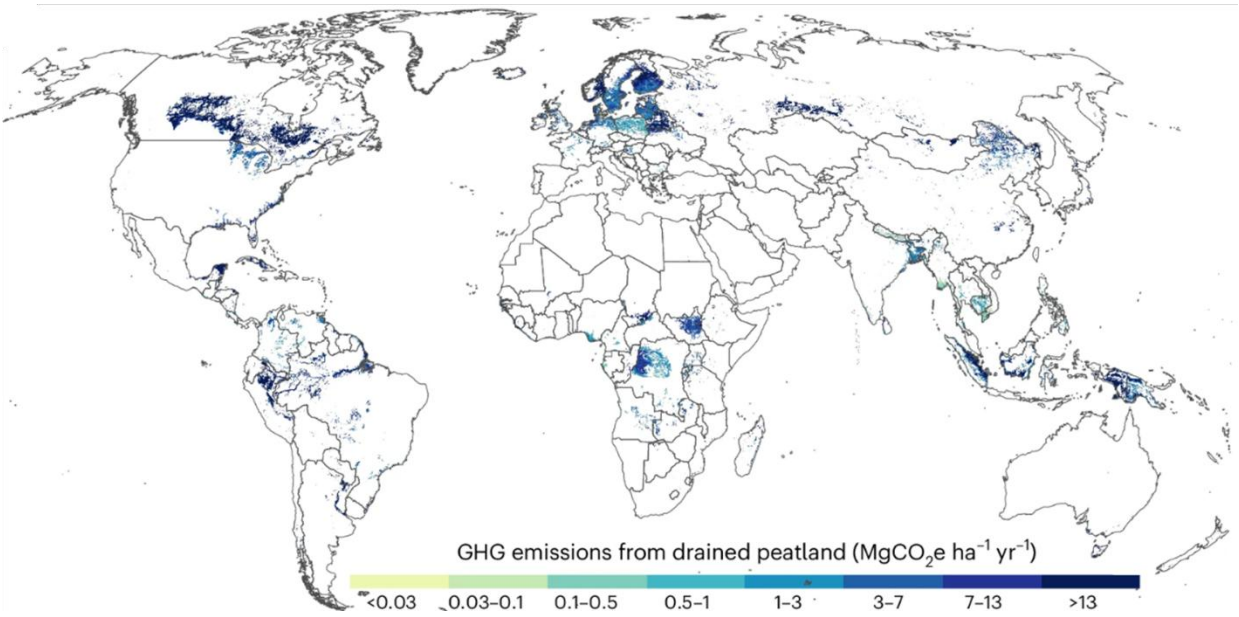


Figure 7: Emissions from drained peatland include CO_2, CH_4 and N_2O (Cao, P. et al. 2026).

The baseline emission per hectare for a specific country is determined by dividing its total cropland emissions by the total physical cropland area as reported by Cao et al. (2026).

$$BE_x = \frac{\text{Emission}_x \text{ (kg } CO_2 \text{ or } N_2O)}{\text{Physical area (ha)}}$$

BE_x = Baseline emission (kg CO_2 or N_2O / ha)

Emission_x = Total Emissions of Cropland (kg CO_2 or N_2O)

Physical area = Total crop physical cropland area (ha)

3.5.9.2 Crop specific peat emissions

To obtain crop-specific emissions for the 46 crops (0) identified by Cao et al. (2026), the baseline emissions of a Cao et al. (2026) were evaluated against the calculated baseline emissions from the same study. Note that NIR emissions were never used to calculate the correction factor. This comparison served to derive a crop-country specific correction factor.

$$CF_x = \frac{\text{Emissions}_{crop}}{BE_x}$$

CF_x = Correction factor (CO_2 or N_2O)

Emissions_{crop} = Crop specific emissions (kg CO_2 or N_2O / ha)

BE_x = Base emission (kg CO_2 or N_2O / ha)

The final crop specific emission values were determined by applying the correction factor (CF_x) to the respective national emission baseline. These baselines were established using either NIR data if available, or Cao et al. (2026) data, if no NIR was present.

$$\text{Emission}_x = \text{NBE}_x * \text{CF}_x \text{ (if available)}$$
$$\text{Emission}_x = \text{BE}_x * \text{CF}_x$$

$Emissions_x$ = Final emissions per ha.

NBE = NIR Base emission (kg CO_2 or NO_2 / ha)

CF_x = Correction factor

BE_x = Base emission (kg CO_2 or N_2O / ha**)**

As national inventory reports do not contain CH_4 peat emissions, the emissions of CH_4 as reported by Cao et al. (2026) are always used as peat methane emissions in Agri-footprint. Note that the methods used for the determination of peat emissions in the national inventory reports are country specifically determined. Reporting countries may use methodology that is best tailored to their local environment.

3.5.10 Regionalized emissions and resources

In previous versions of Agri-footprint, only water use was regionalized. With that we mean that within the LCI itself, the region is specified. For example, water use in the Netherlands would have the have the substance name of “Water, unspecified natural origin, NL”, as stated in chapter 3.2.2.2. In recent SimaPro updates, more regionalized substances have been added that are also relevant for Agri-footprint. The names of certain emissions or resources have been changed to enable regionalization. The following substances are now also regionalized in Agri-footprint LCIs.

Table 3-13: Update and regionalized substances in Agri-footprint, with Netherlands as an example

Substance name Agri-footprint 5	Substance name Agri-footprint 6-8
Occupation, annual crop	Occupation, annual crop, NL
Occupation, permanent crop	Occupation, permanent crop, NL
Occupation, grassland/pasture/meadow	Occupation, grassland/pasture/meadow, NL
Transformation, from annual crop	Transformation, from annual crop, NL
Transformation, from forest, unspecified	Transformation, from forest, extensive, NL
Transformation, from grassland	Transformation, from grassland/pasture/meadow, NL
Transformation, from permanent crop	Transformation, from permanent crop, NL
Transformation, to annual crop	Transformation, to annual crop, NL
Transformation, to grassland	Transformation, to grassland/pasture/meadow, NL
Transformation, to permanent crop	Transformation, to permanent crop, NL
Ammonia	Ammonia, NL
Nitrogen monoxide	Nitrogen monoxide, NL
Nitrate	Nitrate, NL
Phosphorus	Phosphorus, NL
Water, unspecified natural origin, NL	Water, unspecified natural origin, NL

Depending on the environmental impact used within LCA software, regionalization can lead to different but more specific environmental impact results.

3.5.11 Specific emissions

3.5.11.1 Methane emissions in rice cultivations

Methane emissions from rice cultivation represent a significant contributor to the environmental impact of agricultural systems, driven by the anaerobic decomposition of organic matter in flooded fields. To quantify these emissions, a tier-structured approach for Agri-footprint is applied conforming to the IPCC (Vol.4, Chapter 5, 2019).

EQUATION 5.2 (UPDATED)
ADJUSTED DAILY EMISSION FACTOR (TIER 1)

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o$$

Where:

EF_i	= adjusted daily emission factor for a particular harvested area
EF_c	= baseline emission factor for continuously flooded fields without organic amendments
SF_w	= scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)
SF_p	= scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)
SF_o	= scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

Figure 8: IPCC Equation 5.2 Adjusted daily emission factor (Tier 1)

The methodology harmonized multi-source spatial, statistical and life cycle inventory datasets to calculate an area-weighted emission factor. Four steps are included:

1. **Baseline harvest area**

From FAO statistics, a five-year average baseline is used to determine per country the area harvested for rice. (2019-2023)

2. **Spatial disaggregation into rice production ecosystems**

Methane production varies across different water management regimes; therefore, the total harvested area is disaggregated into distinct rice production ecosystems based on IPCC terminology, retrieved from Cao, et al. (2026). Including the following rice production ecosystems:

- Rainfed – drought prone
- Rainfed – deep water
- Rainfed – upland
- Rainfed – regular rainfed
- Irrigated – continuously flooded
- Irrigated – multiple drainage
- Irrigated – single drainage

To derive country-specific spatial distribution for these ecosystems, ratios are extracted from IFPRI (2024). For each country, ratios are applied per specific harvested area (Appendix VIII).

3. Calculation of parameterized daily emission factors

The calculation of rice methane follows the adjusted emission factor (Efi) as shown in Figure 8. The baseline factor is adjusted using scaling factors that account for specific water regimes, organic inputs and soil characteristics. To enhance the precision of the organic amendment scaling factor (SFo), this methodology complements standard IPCC default parameters with inventory data from the Agri-footprint database. Data inputs regarding the amount of manure and straw incorporation are derived from Agri-footprint.

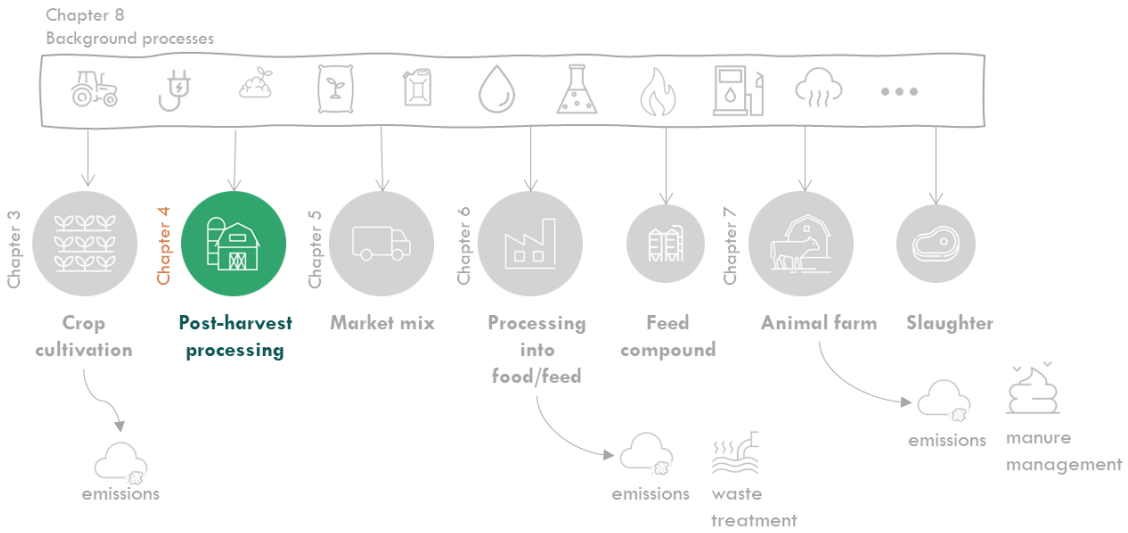
4. Ecosystem methane quantifying

To translate daily emissions into annual totals, the adjusted daily emission factor is multiplied by the ecosystem-specific cultivation length. The cultivation period for each rice production system is derived from MAPSPAM. The total is then divided by the total harvested area to yield a single, area-weighted average methane emission factor per hectare.

Limitations

Limitation of this approach is that the emissions of crop residue burning are omitted from this approach. Additionally, FAO provides country-wide data whereas MAPSPAM includes more granularity which leads to scaling inconsistencies. Tier 1 modelling according to the IPCC is very binary. The scaling factors have limited variations, therefore newer developments in agricultural practices are not well-represented. Any methane emissions outside of the cultivation period are not included

4. Processing of crops at post-harvest



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

Depending on the type of agricultural product, the following post-harvesting steps are considered in Agri-footprint 8:

Table 4-1 Overview of post-harvest activities applied

Product group	Crops	Post-harvest activity
Cereal grains	Barley, maize, oats, rice, rye, sorghum, triticale, wheat, buckwheat, canary seed, millet	Drying
Roots and tubers	Potatoes, onions and sweet potatoes	Cooling
Sugar crops		No activity considered
Pulses	Beans, field peas, broad beans, chickpeas, lupins, pigeon peas, lentils, vetches	Drying
Oil bearing crops	Groundnuts, linseed, mustard seed, rapeseed, sesame, soybeans, sunflower seed, hempseed, poppy seed, safflower seed, seed cotton	Drying
Vegetables		No activity considered
Nuts	Coconut, groundnut, almonds	Deshelling/dehusking

4.1 Deshelling/dehusking

The post-harvest deshelling and dehusking processes are relevant for modelling groundnut and coconut value chains within Agri-footprint. These mechanical separation steps alter the physical mass balance by removing outer protective layers, which are typically treated as residues or co-products. For groundnuts, the shell fraction represents approximately 30%, based on the FAO (2001b) (groundnuts in shell are converted at 70% and reported on a shelled basis), of the total fresh harvest weight. For coconuts, the combined shell and husk fraction accounts for 39% of the total input mass, derived from primary mass balance data provided by a commercial processor in Sri Lanka.

Due to a lack of crop-specific primary inventory data for processing energy across all evaluated systems, energy consumption for both groundnuts and coconuts is modelled using a generic default value. This default is calculated as the unweighted average energy demand (electricity and diesel). Values are in Table 4-2.

Table 4-2 Electricity and diesel use of nuts used for deriving a nut deshelling default.

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

4.2 Drying of crops

In previous versions of Agri-footprint, the drying of crops was based on default values for heat and electricity use for certain crops only. Since Agri-footprint 6, more country specific data was used to determine the energy use for drying crops. Data on humidity of harvested crops from Eurostat was used in order to determine the humidity of crops before drying (Eurostat, 2021a). A 5-year average value (2014-2018) was used to incorporate yearly differences in humidity of crops when harvested. For crops which are not reported in Eurostat, the crop group average values were used. Hereby drying is consistently applied for all crops within the same crop group. An overview of Agri-footprint crops, crop group, Eurostat crop and safe humidity values for storage are shown in Table 4-3.

Table 4-3 Humidity values for crop storage (FAO, *Survey and Analysis of Post-Harvest Losses* (n.d.)).

Agri-footprint crop	Crop group	Eurostat crop	Humidity storage
Wheat grain	Cereals	Wheat and spelt	12%
Rye grain	Cereals	Rye	12%
Barley grain	Cereals	Barley	12%
Oat grain	Cereals	Oats	12%
Triticale grain	Cereals	Triticale	12%
Sorghum grain	Cereals	Sorghum	12%
Rice grain	Cereals	Rice	12%
Other cereals	Cereals	Cereals and cereal products	12%
Peas, dry	Pulses	Field peas	10%
Broad beans	Pulses	Broad and field beans	10%
Lupins	Pulses	Sweet lupins	10%
Other pulses	Pulses	Other dry pulses and protein crops n.e.c.	10%

Rapeseed	Oil bearing crops	Rape and turnip rape seeds	8%
Sunflower seed	Oil bearing crops	Sunflower seed	8%
Soybeans	Oil bearing crops	Soya	8%
Linseed	Oil bearing crops	Linseed (oilflax)	8%
Other oil-bearing crops	Oil bearing crops	Other oilseed crops n.e.c.	8%

Based on the humidity of the crop from Eurostat (2014-2018 period) and the safe humidity of storage derived from FAO (FAO, 1994) it can be calculated how much water needs to be evaporated from crop to reach the desired humidity. This is calculated using the following equation:

$$Amount\ water\ (kg\ water\ per\ ton\ stored\ product) = \left(\frac{1 - DM\ crop\ safe\ storage}{1 - DM\ crop\ harvest} * 1000\ kg\right) - 1000$$

Equation 4-1

Where:

DM crop safe storage is taken from Table 4-3.

DM crop harvest is taken from Eurostat, 5-year average (2014-2018).

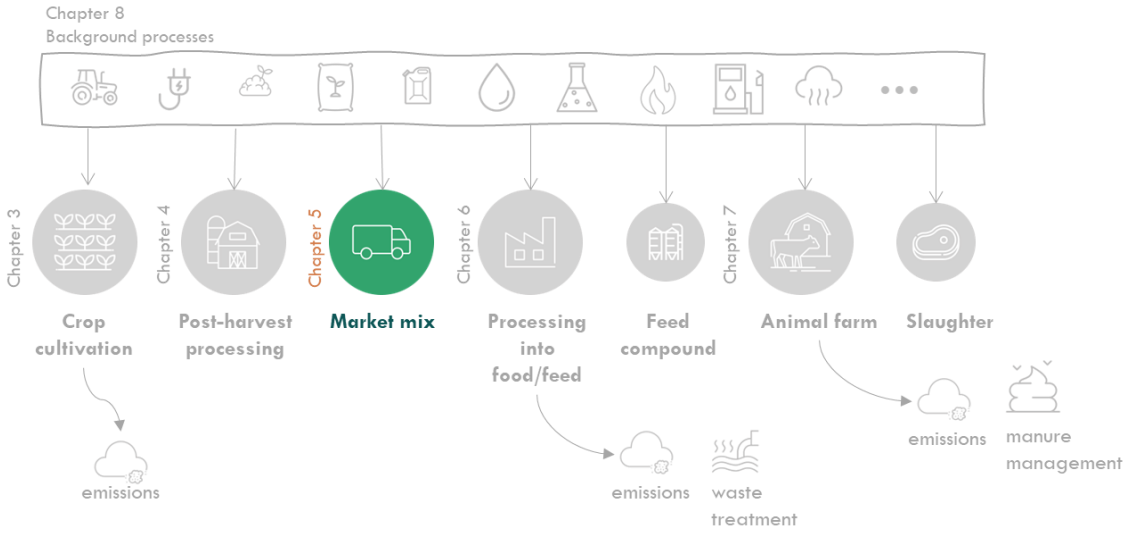
For all European countries, the dry matter crop harvest is country specific data from Eurostat is used (2014-2018 period). For all other countries the dry matter crop harvest EU average is taken as default. For future Agri-footprint versions, we intend to use more specific data for all non-European countries.

For all grains, pulses and oilseeds, it is assumed that FAOSTAT reports agricultural yields in their traded, dried state; consequently, moisture loss is excluded from the calculations to prevent double counting, whereas the associated drying energy is fully incorporated. The drying is assumed to be performed by a fluid bed dryer, using 150 MJ electricity per ton of water evaporated and 4500 MJ steam per ton of water evaporated based on (Fox et al., 2010).

4.3 Cooling of crops

For onions, sweet potatoes and potatoes, it is assumed that crops are cooled during storage. A default value of 30 kWh/ton is assumed for all countries. The default value of 30 kWh/ton is derived from a commercial party specialized in cooling (confidential source). The time spent is not considered.

5. Market mix of commodities



In Agri-footprint 8, the market mixes of raw materials and processes commodities have been updated. The market mixes of commodities also contain the transportation requirements for transporting the materials from the various sources to the specific country market, based on transportation distances from the PEFCR Feed (European Commission, 2018a).

5.1 Market mix of raw materials

The market mix of specific raw materials is determined by adding the total import of the raw materials from various countries (FAO, 2026d) to specific country with the national production of the same product (FAO, 2026a). To overcome huge trade and production fluctuations from year to year, 5-year averages are used (2019-2023). For the underlying trading countries, a market mix is constructed to determine the source country of the raw material. This can be best explained using an example, as shown in **Error! Reference source not found.**.

An example is shown in Figure 9: Sankey representation of how market mixes are calculated in Agri-footprint.: Country A is 10% self-sufficient and imports 20% from country B, 30% from country C and 40% from country D. Building a market mix based on the “first layer approach” is quite problematic, since it is quite possible that a specific county only acts as transit country or imports a lot from other countries. Therefore, for each country that trades with country A directly (country B, C and D), their market mixes are inventoried as well. By default, Agri-footprint inventories at least 4 levels deep in order to determine the cultivation countries of the commodity in country A. Since country D does not produce the commodity itself, but only acts as a transit country, it is not part of the final market mix of the commodity in country A, whereas country F, even though it does not trade directly with A, is the largest cultivator of the commodity in country A.

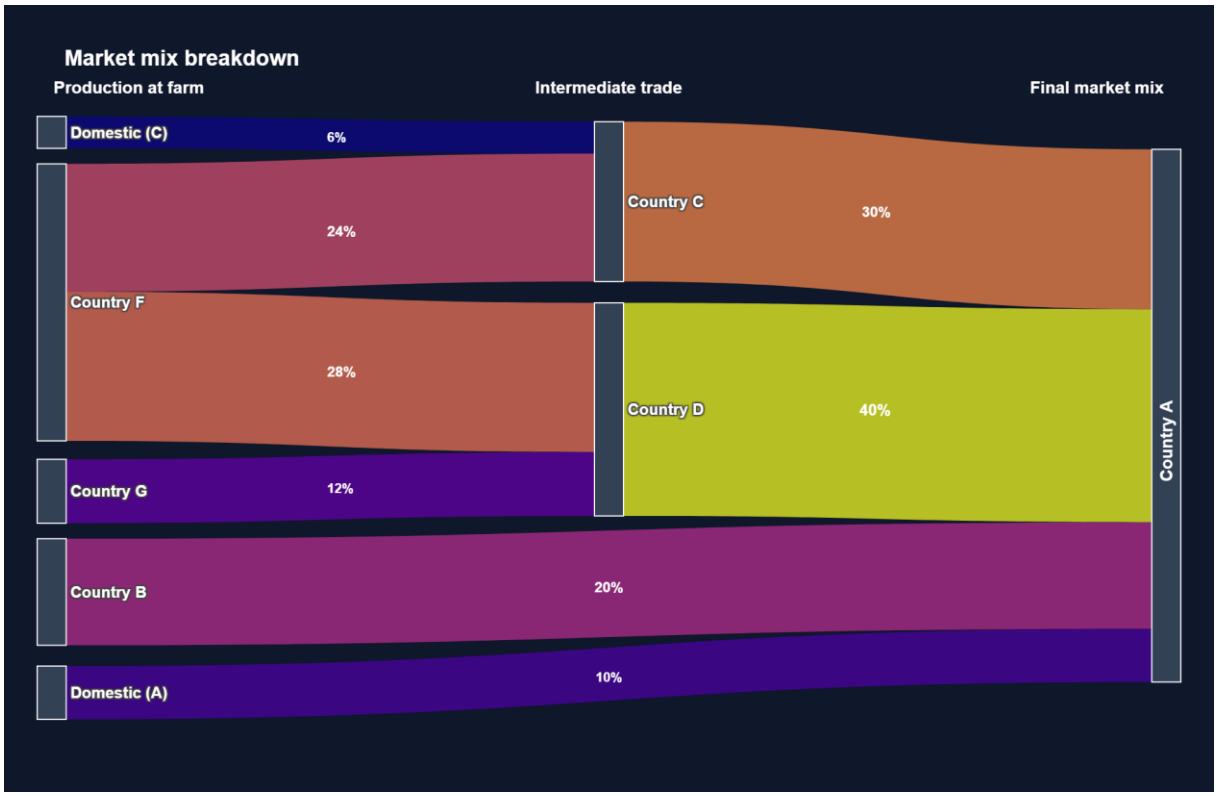


Figure 9: Sankey representation of how market mixes are calculated in Agri-footprint.

Agri-footprint does not contain cultivation data for all countries. How the final market mix is eventually determined can be best illustrated using an example as shown Table 5-1.

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

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

Based on the trade and production statistics that are available for maize, 98.4% of all available maize on the Dutch market is from 15 different countries. 1.6% of the market mix comes from countries providing less than 0.5% of the market mix and are therefore excluded. Also, Agri-footprint does not contain maize cultivation data for all countries. In the fictive example above, this means that maize cultivation in the Netherlands, Serbia and Russia is excluded from the Dutch market mix. For the datasets for which cultivation data is available, the coverage determines the quality of the market mix. In the case of maize on the Dutch market, 89.2% of maize cultivation data is available. The final market mix is scaled based on the relative shares of the different countries totaling 100%. For each market mix, the coverage information is given in the comment field of the market mix LCI. For the market mix a rule of coverage > 50 % is required to be included, the exceptions are reported in Appendix XI

5.2 Market mix of processed materials

The same principle that is used for raw materials is also used for processed materials. Combining trade data with national production of processed crops (FAO, 2018b). Production data for processed crops is quite limited. But with some additional information production data of co-products were inventoried as well. For example: in FAOstat only the quantity of soybean oil is given. By using a fixed soybean oil to soybean meal yield ratio, the amount of soybean meal production can be quantified as well. An overview of additional inventoried processed commodities is given in Table 5-2. Most of the inventories were created by an averaging procedure of industry data by Van Zeist et al. (2012).

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

Production data	Production inventoried	Ratio (Data/inventoried)	Comment / source:
Groundnuts, with shell	Groundnuts, shelled	0.7	For trade data, groundnuts in shell are converted at 70% and reported on a shelled basis. (FAO, 2001)
Rice, paddy	Rice - total (Rice milled equivalent)	0.625	Industry average[7]
Oil, coconut (copra)	Cake, copra	0.604	Coconut copra meal (Van Zeist et al., 2012)
Oil, cottonseed	Cake, cottonseed	2.658	Feedprint: Cottonseed (Van Zeist et al., 2012)
Oil, groundnut	Cake, groundnuts	1.053	Feedprint: Peanut solvent crushing solvent extraction (Van Zeist et al., 2012)
Oil, linseed	Cake, linseed	1.829	Feedprint: linseed solvent extraction (Van Zeist et al., 2012)
Oil, maize	Cake, maize	1.871	Maize germ meal expeller, wet milling (Van Zeist et al., 2012)
Oil, palm kernel	Cake, palm kernel	1.128	Palm kernel expeller (Van Zeist et al., 2012)
Oil, rapeseed	Cake, rapeseed	1.390	Rapeseed meal, solvent (Van Zeist et al., 2012)
Oil, sesame	Cake, sesame seed	1.373	Feedprint: Sesame solvent extraction (Van Zeist et al., 2012)
Oil, soybean	Cake, soybeans	3.693	Soybean meal, solvent (Van Zeist et al., 2012)

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

Oil, sunflower	Cake, sunflower	1.250	Sunflower seed meal (Van Zeist et al., 2012)
Sugar beet	Sugar Raw Centrifugal	0.128	Sugar, from sugar beet (Van Zeist et al., 2012)
Sugar cane	Sugar Raw Centrifugal	0.132	Sugar, from sugar cane (Van Zeist et al., 2012)

5.3 Transportation requirements for market mixes

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

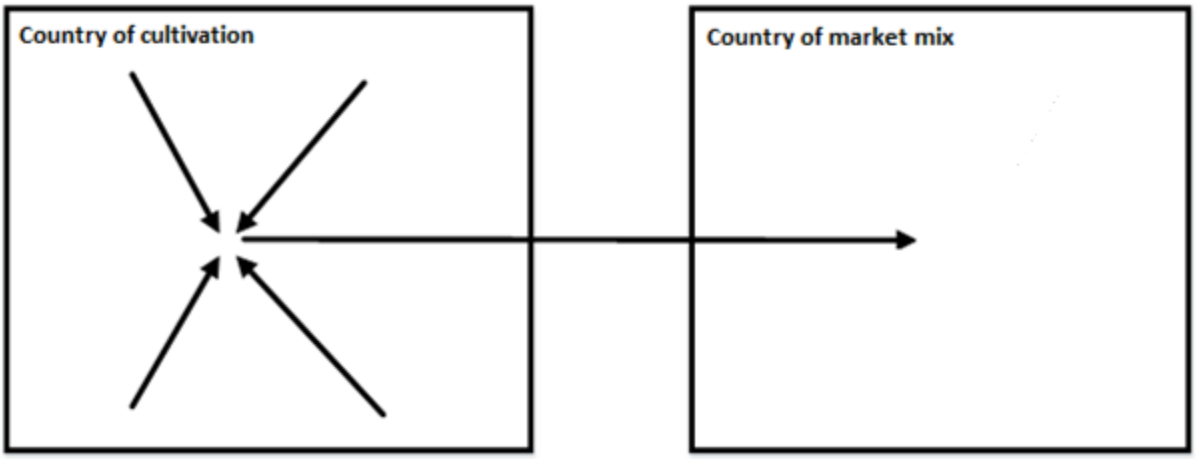


Figure 10: Generic transport model from a central hub in land of cultivation to the market location within a specific country.

5.3.1 Data collection

The transport model of Feedprint (Vellinga et al., 2013b) has been used as a basis but has been updated and extended to cover all relevant transport flows for new cultivation countries. When no transport distance was covered in our model, the transport distances have been based on the transport distances described in Annex 6 of the PEFCR Feed (European Commission, 2018b). For transport from outside of EU the EU default is used. For domestic transport and transport inside of the EU, the European default has been used.

Table 5-3: Transport rules applied per region in the Market mixes.

PEFCR standard	Truck > 20t	Freight train	Barge ship	Sea ship
EU default	130	240	270	-
non-EU default	1000	-	-	18000

5.4 Production mix of raw materials

A production mix is a weighted average of the crop production LCI's in a specified region. Each country LCI proportion is determined by the total production per country as reported by FAO (FAO, 2026a). Currently only regions RER and GLO are supported in the creation of production mixes.

For consistency, the same 5-years period (2019-2023) is used to create the averages that are aligned with the market mix data. The production mixes do not contain transport data and should be treated as process at farm gate. For some countries there is no cultivation data available in Agri-footprint for a complete production mix. Those missing countries are excluded from the production mix, and existing countries are rescaled to 100% to make up for the missing share of the production mix. As a rule for production mix, the required coverage minimum value defined is 50 %, the exceptions are reported in Appendix XI. These production mixes can be used as proxies for missing geographies of the same commodity, as specified by the PEFCR of Feed (European Comission, 2018).

For the datasets for which cultivation data is available, the coverage determines the quality of the market mix. In the case of maize on the Dutch market, 89.2% of maize cultivation data is available. The final market mix is rescaled based on the relative shares of the different countries totaling 100%.

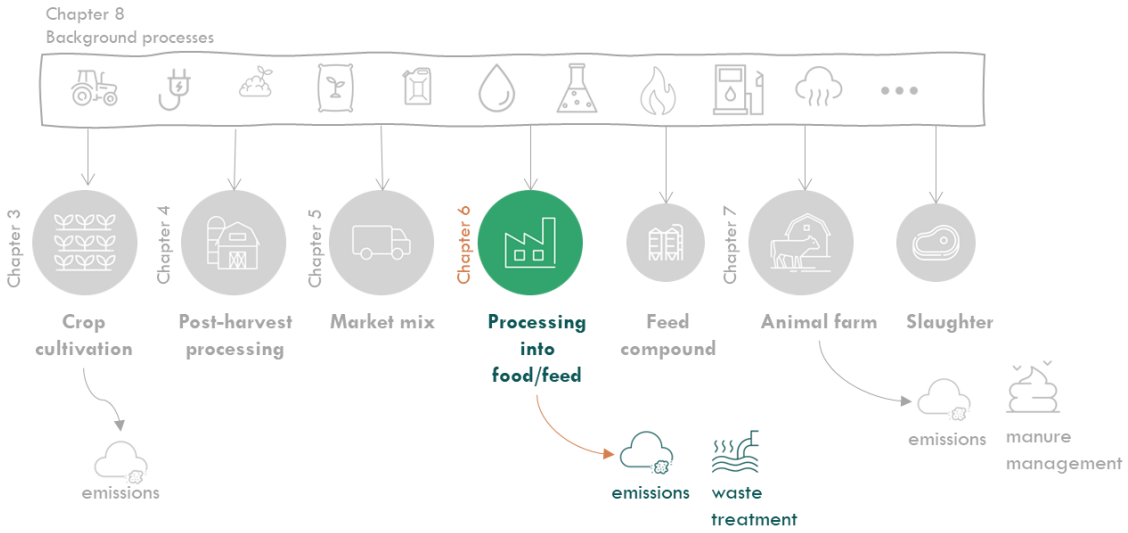
5.5 Group Totals Production

The group totals is a fallback strategy for unknown feed components as suggested by the PEFCR feed (European Commission, 2024). It represents the cumulative value of all the feed, calculated at a global level, divided into sub-groups and rescaled to 1000 kg. The “Total all group” is built by sub-group totals (Table 5-4), representing the mass proportion of each sub-group, for 3 different geographies: Global (GLO), Europe (RER) and Netherlands (NL) were calculated using the Global total production as reference. Per region the totals are built on market mixes for that specific region. The transport rules for the group total production are the same as used the market mix (Table 5-3). The listed groups and their global production (kg) are:

Table 5-4: Total groups production groups and their total mass weight.

Group Name	Total (kg)
Total all groups, at processing.	1000
Total vegetable oils, at processing.	6
Total pulses, dried, at processing.	13
Total cereals, dried, at processing.	480
Total co-products, at processing.	150
Total other, at processing.	13
Total minerals, additives, vitamins, at plant.	36
Total vegetable meals, at processing.	276
Total dried forages, at processing.	14
Total animal origin, at processing.	19
Total tapioca, at processing.	1

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



6.1 Introduction and reader's guide

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

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

Crop/animal products	Feed products	Food products	Source and original region of data
Animal products	Fat from animals Greaves meal Animal meal Blood meal	Food grade fat Cream (full fat)	(Van Zeist et al., 2012a) (European Commission, 2005) (Safriet, 1995)
	Fish meals Fish oils		(Cashion et al., 2016a, 2017a; Van Zeist et al., 2012a)

Crop/animal products	Feed products	Food products	Source and original region of data
	Milk powder (skimmed) Milk powder (full fat) Whey powders	Cream (skimmed) Milk powder (skimmed) Milk powder (full fat) Milk standardized (full fat) Milk standardized (skimmed) Cheese	(Van Zeist et al., 2012a) (Sheane et al., 2011)
Cereal products	Brewer's grains		(Van Zeist et al., 2012c)
	Maize germ meal expeller Maize germ meal extracted Maize gluten meal dried Maize gluten meal wet Maize gluten feed dried Maize gluten feed wet Maize solubles Maize starch dried Crude maize germ oil	Maize flour Maize starch Refined maize germ oil	(Van Zeist et al., 2012c, 2012f) (Eijk & Koot, 2005) (Bolade, 2009) (Bechtel et al., 1999)
	Oat grain peeled Oat husk meal Oat mill feed high grade	Oat grain peeled	(Van Zeist et al., 2012c)
	Rye middlings	Rye flour	(Van Zeist et al., 2012c)
	Wheat bran Wheat germ Wheat gluten feed Wheat gluten meal Wheat middlings & feed Wheat starch slurry	Wheat starch Wheat flour	(Van Zeist et al., 2012c, 2012f)
	Rice bran meal Rice feed meal Rice husk meal Crude rice bran oil	White rice Brown rice Rice brokens Refined rice bran oil	(Goyal, S. et al. 2012) (Blengini and Busto, 2009) (Roy, P. et al 2007)
Oilseed products	Coconut copra meal Crude coconut oil	Refined coconut oil	(Van Zeist et al., 2012b)

Crop/animal products	Feed products	Food products	Source and original region of data
	Palm kernel expeller Palm kernels Crude palm oil Fatty acid distillates	Refined palm oil Refined palm kernel oil	(Van Zeist et al., 2012b)
	Rapeseed expeller Rapeseed meal	Refined rapeseed oil	(Van Zeist et al., 2012b) ((S&T)2 Consultants, 2010) (Schneider & Finkbeiner, 2013)
	Crude soybean oil Soybean protein-concentrate Soybean expeller Soybean hull Soybean lecithin Soybean meal Soybean okara Soybean, heat treated Soybean molasses Soybean slurry Soybean fined	Refined soybean oil Soybean protein-concentrate Soybean protein-isolate	(Van Zeist et al., 2012b) (Sheehan et al., 1998) (OTI, 2010) (Schneider & Finkbeiner, 2013) (Van Veghel, 2017)
	Sunflower seed dehulled Sunflower seed expelled dehulled Sunflower seed meal	Refined sunflower oil	(Van Zeist et al., 2012b)
	Groundnut meal Crude groundnut oil		(Van Zeist et al., 2012b)
	Linseed expeller Linseed meal Crude linseed oil	Refined linseed oil	(Van Zeist et al., 2012b)
Legume products	Broad bean hulls	Broad bean meal	(Broekema & Smale, 2011)
	Lupins fibre Lupins hull Lupins okara Lupins protein slurry	Lupins oil Lupins protein-concentrate Lupins protein-isolate	(Van Veghel, 2017)

Crop/animal products	Feed products	Food products	Source and original region of data
	Pea wet animal feed Pea starch-concentrate Pea slurry	Pea protein-isolate Pea protein-concentrate Pea starch slurry	(Van Veghel, 2017)
Roots & tubers products	Cassava root dried Cassava peel Cassava pomace (fibrous residue)	Tapioca starch	(Chavalparit & Ongwandee, 2009) (Van Zeist et al., 2012d)
	Potato juice concentrated Potato pulp pressed fresh + silage Potato pulp dried	Potato protein Potato starch dried	(Van Zeist et al., 2012f)
Fruit and vegetable products	Citrus pulp dried		(Van Zeist et al., 2012d)
Sugar products	Sugar beet molasses Sugar beet pulp wet Sugar beet pulp dried	Sugar from sugar beet	(Van Zeist et al., 2012e) (Klenk et al., 2012)
	Sugar cane molasses	Sugar from sugar cane	(Van Zeist et al., 2012e)

6.1.1 Waste in processing

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

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

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

6.1.2 Water use in processing

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

use data from an analogous process for a different crop were used as a proxy. The water use sources for a specific process are indicated in the next chapters.

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

6.1.3 Energy use in processing

For energy use, system processes based on the ecoinvent database are used. Electricity use is country or region specific based on ecoinvent. If there is not a country- or region-specific option available for the relevant country, a “Rest of world” (RoW) process is used instead. Heat from natural gas is regionalized only as either from Europe (Europe without Switzerland) or not (RoW). Heat from either light fuel oil or heavy fuel oil is not regionalized and only RoW processes are used for these types of processes.

Table 6-2. List of energy sources used based on ecoinvent

List of energy sources used
Electricity, low voltage {…}| market for electricity, low voltage | Cut-off, S - Copied from ecoinvent
Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | Cut-off, S - Copied from ecoinvent
Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | Cut-off, S - Copied from ecoinvent
Heat, district or industrial, other than natural gas {RoW}| heat production, heavy fuel oil, at industrial furnace 1MW | Cut-off, S - Copied from ecoinvent
Heat, district or industrial, other than natural gas {RoW}| heat production, light fuel oil, at industrial furnace 1MW | Cut-off, S - Copied from ecoinvent

6.1.4 Auxiliary material/other ingredients in processing

Several other inputs are used in the processing LCI’s. For some of the auxiliary material the production process is modelled in Agri-footprint database. The description of these can be found in chapter 8. Other auxiliary materials and input used are based on the ecoinvent database (system processes) as listed in Table 6-3.

Table 6-3 Auxiliary material used in various processes, based on background system processes from ecoinvent.

Auxiliary material/Other ingredients	Process
Sodium chloride, powder {GLO}| market for sodium chloride, powder | Cut-off, S – Copied from ecoinvent	Swine compound feed production
Sulfur {GLO}| market for sulfur | Cut-off, S – Copied from ecoinvent	Cassava, sugar beet and sugar cane processing
Limestone, unprocessed {RoW}| market for limestone, unprocessed | Cut-off, S – Copied from ecoinvent	Sugar beet processing
Base oil {RoW}| base oil production, petroleum refinery operation | Cut-off, S - Copied from ecoinvent	Soybean crushing
Nitrogen, liquid {RER}| market for nitrogen, liquid | Cut-off, S - Copied from ecoinvent	Various oil refining

6.2 Animal products

6.2.1 Meat co-products

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

6.2.2 Dairy products

Dairy products are consumed worldwide due to their importance on the human diet. However, the production of milk, its fundamental component, consumes significant natural resources (Egas et al., 2020). In alignment with the Product Environmental Footprint Category Rules (PEFCR) for Dairy Products (EDA, 2021), life cycle inventories show that the primary environmental hotspots across key products like cheese, skimmed milk, cream, and liquid whey, are raw milk production, thermal energy from natural gas combustion, and grid electricity consumption.

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

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

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

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

Further processing of whey into a variety of products was based on primary data representing the main part of dairy processing industry in the Netherlands. The mass balances and allocation factors were based on primary data, while energy inputs were modelled based on (Schuck et al., 2015).

Minor inputs and processing aids, including salt, calcium chloride, rennet, and bacterial or yeast cultures, were excluded from the system boundaries under standard PEF cut-off criteria due to their negligible contribution to total environmental emissions.

6.2.3 Wild caught fish products

Agri-footprint contains two types of wild caught fish LCIs:

- Generic wild caught fish LCIs: which is based on the generic energy needs for capturing fish used for feed, derived from Feedprint (van Zeist et al., 2012a), The same inventory is available for multiple regions and acts as input for the processing step. processing, described in chapter 6.2.3.

- Specific wild caught fish. LCIs: which is based on fish and region-specific energy needs for capturing fish is derived from Cashion et al. (2017).

Fish	Region	Energy use	Source:
Generic fish	All	1.5625 MJ/kg	van Zeist et al., 2012a
Alaska pollock	Norway	3620 MJ/ton	pelagic trawl fishery (Cashion et al. 2017)
Anchoveta	Peru	766 MJ/ton	purse seine fishery (Cashion et al. 2017)
Atlantic herring	Norway	1831 MJ/ton	purse seine fishery (Cashion et al. 2017)
Atlantic menhaden	United States	1235 MJ/ton	purse seine fishery (Cashion et al. 2017)
Blue whiting	Norway	3620 MJ/ton	purse seine fishery (Cashion et al. 2017)
Capelin	Norway	980 MJ/ton	purse seine fishery (Cashion et al. 2017)
Cod	Norway	22700 MJ/ton	mixed gear fishing (Cashion et al. 2017)
European pilchard	Norway	4642 MJ/ton	purse seine fishery (Cashion et al. 2017)
Gulf menhaden	Mexico	1576 MJ/ton	purse seine fishery (Cashion et al. 2017)
Haddock	Norway	28918 MJ/ton	mixed gear fishing (Cashion et al. 2017)
Krill	Norway	6005 MJ/kg	pelagic trawl fishery (Cashion et al. 2017)
Mackerel	Norway	3600 MJ/ton	purse seine fishery (Cashion et al. 2017)
Sand eel	Norway	6346 MJ/kg	bottom trawl fishery (Cashion et al. 2017)
South American pilchard	United states	4259 MJ/kg	purse seine fishery (Cashion et al. 2017)
Sprat	Norway	15800 MJ/kg	pelagic trawl fishery (Cashion et al. 2017)

6.2.4 Fish co-products

General processing of landed fish and offal, from fishery into fish oil and meal is based on Feedprint (Van Zeist et al., 2012a) and other literature sources (Jespersen et al., 2000; Olesen & Nielsen, 2000; N. Pelletier et al., 2009; N. L. Pelletier, 2006).

In addition, marine ingredients yielding from reduction of a variety of specific fish sources are modelled, as listed in

Table 6-4. The yield data and energy needed for processing are from (Cashion et al., 2016b, 2017b). By lack of specific price data, prices for general fish meal and fish oil are used to calculate allocation shares (1454 USD/ton fish meal and 1703 USD/ton fish oil, OECD stats 5-year average 2018-2022). (Cashion et al., 2016) also reports energetic contents for the fish meals separately and a general energy content for fish oil, which are used for allocation on energy basis.

Table 6-4. Fish meals and oils from fish reduction

Source	Output	Yield from 1t input (kg)	Economic allocation share
Alaska pollock by-products	Fish meal, from Alaska pollock	170	89.5%
	Fish oil, from Alaska pollock	17	10.5%
Anchoveta	Fish meal, from Anchoveta	240	80.4%
	Fish oil, from Anchoveta	50	19.6%
Atlantic menhaden	Fish meal, from Atlantic menhaden	240	80.4%
	Fish oil, from Atlantic menhaden	50	19.6%
Blue whiting	Fish meal, from Blue whiting	197	89.8%
	Fish oil, from Blue whiting	19	10.2%
Capelin	Fish meal, from Capelin	165	64.7%
	Fish oil, from Capelin	77	35.3%
Cod by-products	Fish meal, from Cod by-products	170	89.5%
	Fish oil, from Cod by-products	17	10.5%
European pilchard (sardine)	Fish meal, from European pilchard (sardine)	230	52.2%
	Fish oil, from European pilchard (sardine)	180	47.8%
Gulf menhaden	Fish meal, from Gulf menhaden	210	52.8%
	Fish oil, from Gulf menhaden	160	47.2%
Haddock	Fish meal, from Haddock	170	89.5%
	Fish oil, from Haddock	17	10.5%
Atlantic Herring	Fish meal, from Atlantic Herring	204	60.8%
	Fish oil, from Atlantic Herring	115	39.2%
Krill	Fish meal, from Krill	160	99.4%
	Fish oil, from Krill	0.80	0.6%
Sand Eel	Fish meal, from Sand Eel	197	79.9%
	Fish oil, from Sand Eel	42.4	20.1%
South American pilchard (sardine)	Fish meal, from South American pilchard (sardine)	230	52.2%
	Fish oil, from South American pilchard (sardine)	180	47.8%
Sprat	Fish meal, from Sprat	188	67.0%
	Fish oil, from Sprat	79	33.0%
Atlantic Herring by-products	Fish meal, from Atlantic Herring by-products	200	81.0%
	Fish oil, from Atlantic Herring by-products	40	19.0%
Mackerel by-products	Fish meal, from Mackerel by-products	194	47.5%
	Fish oil, from Mackerel by-products	186	52.5%

6.2.5 Fish degutting

The edible part of the fish degutting process is derived from “Edible flesh” using fish specific data (FAO, 2013). Generic information on the energy use and emissions from the fish degutting process is derived from various literature sources and applied to all fish (Broekema et al., 2015; Jespersen et al., 2000).

Table 6-5: Edible part and by-products of fish in Agri-footprint, based on FAO (FAO, 2013)

Fish	By products	Edible part
Alaska pollock	0.41	0.59
Atlantic herring	0.39	0.61
Cod	0.53	0.47
Mackerel	0.78	0.22

6.2.6 Fish economic, mass and energy allocation

To calculate the economic allocation, we apply the "share of revenue" distribution. To calculate the mass and energy allocation, the DM and gross energy of the edible part and the by-products are used. We use referenced data listed in the Table 6-6.

Table 6-6: Fish economic, mass and energy allocation.

Fish name	Product	DM (g/kg)	Share of economical revenue	Gross Energy (MJ/kg)	Source
Alaska pollock	Alaska Pollock by-products	350	0.02	7.322	Kandyliari et al. 2020
	Alaska Pollock edible part	208	0.98	4.6035	Sidwell et al., 1974
Atlantic herring	Atlantic Herring by-products	350	0.02	7.322	Kandyliari et al. 2020
	Atlantic Herring edible part	399	0.98	11.2135	Sidwell et al., 1974
Cod	Cod by-products	350	0.02	7.322	Kandyliari et al. 2020
	Cod edible part	189	0.98	4.3423	Sidwell et al., 1974
Mackerel	Mackerel by-products	350	0.02	7.322	Kandyliari et al. 2020
	Mackerel edible part	233	0.98	7.3216	Sidwell et al., 1974

6.3 Cereal Products

6.3.1 Wet milling (maize, wheat)

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

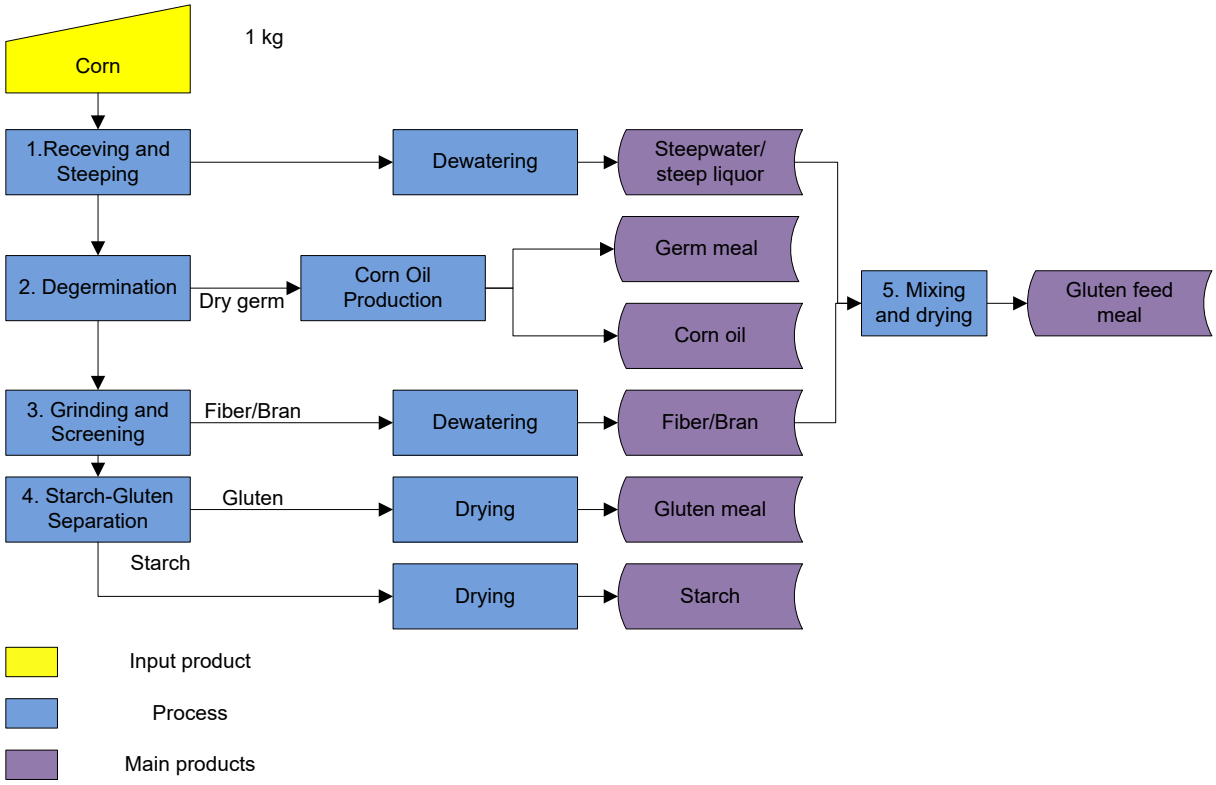


Figure 11: Wet milling of maize (van Zeist et al., 2012f).

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

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

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

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

6.3.3 Dry milling (rice)

This process describes the production of brown rice (rice without husks) and rice husks from a rice dry milling process in China Figure 12. Rice husk meal is typically used as animal feed. Traditionally, the process of de-husking was done manually, but nowadays the de-husking machine consists of a pair of rubber-lined rollers which are mounted in an enclosed chamber. As the rice passes through these rollers the husks are removed by friction leaving the paddy intact.

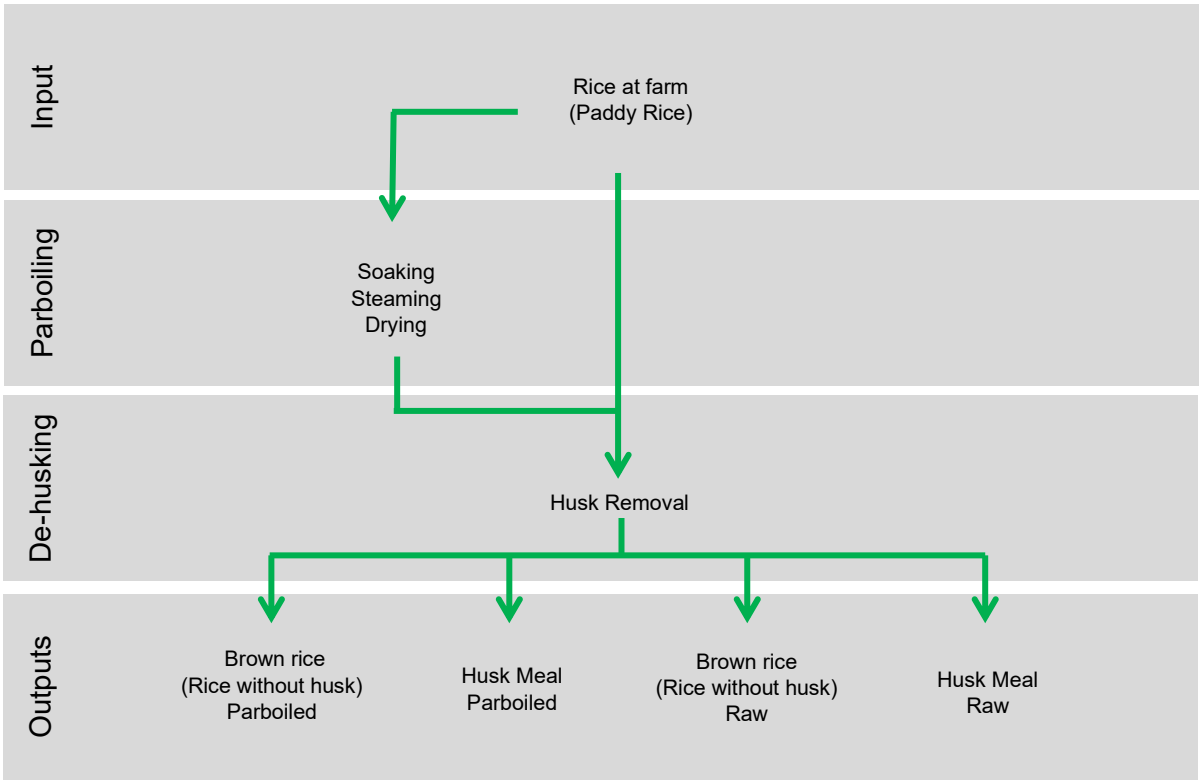


Figure 12: Diagram describing the process of production of rice without husks and rice husks from a rice dry milling process.

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

The brown rice parboiled have the process steps (parboiling and de-husking) aggregated in the inventory and include the use of electricity and steam, while the rice raw does not includes the parboiled process, including only the electricity of the de-husking stage. The mass balance of the process is based on data from (IRRI, 2015a) (but mass of hulls and white rice is combined into a single output). Data on inventory inputs were taken from regional data (Goyal et al., 2012). To ensure the data consistency, the data was compared to other publicly reported data for milling (Blengini & Busto, 2009; Roy et al., 2007). The data showed good agreement with the referenced studies as it showed similar input/output ratios. Water use in dry milling is based on (A. M. Nielsen & Nielsen, 2001).

Another process describes the production of white rice, rice husks, rice bran and rice broken from a rice dry milling process in China (Figure 13**Error! Reference source not found.**). The process starts with paddy rice, followed by parboiling, de-husking and the milling process.

Parboiling before de-hulling is optional, and it is estimated that half of the paddy rice is parboiled before processing. The advantages of parboiling are described above.

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

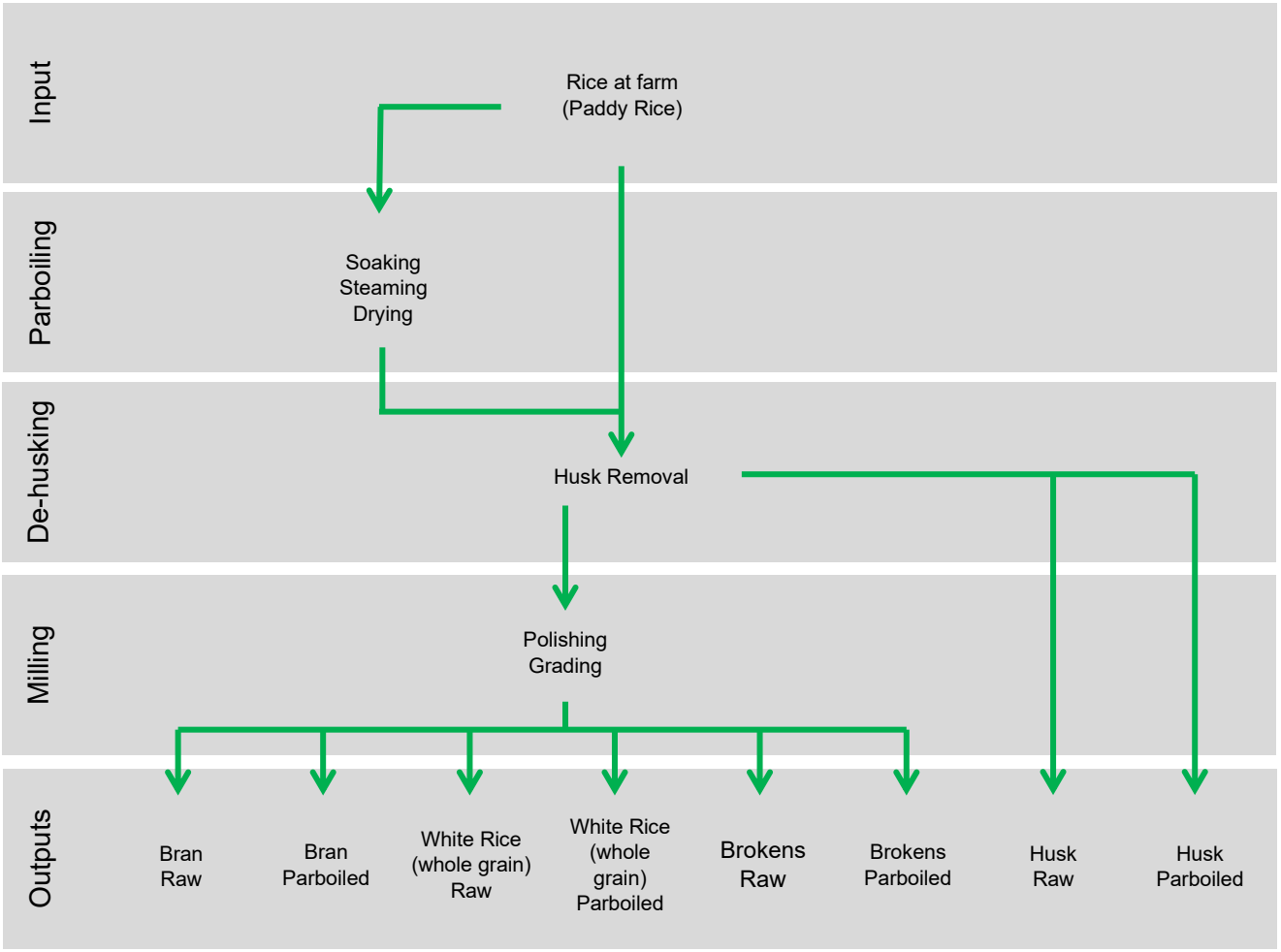


Figure 13: Diagram describing the process of production of white rice, rice husks, rice bran, and rice brokens from a rice dry milling process in China.

6.4 Oilseed products

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

6.4.1 Crushing

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

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

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

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

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

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

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

6.4.1.1 Price data for meals and oils

Table 6-7 shows an overview of product values and allocation percentages. Note that output value per kg has no consistent unit between processes. It might be for example price in USD/ton, price in EUR/ton but also relative values as communicated by industry experts when

actual prices are confidential. Units are always consistent within a process, so the allocation shares are calculated accurately. To update prices of oils and meals/expellers, a 5-year average was taken from FAOSTAT data (2014-2018). Since FAOSTAT does not distinguish between meals (output from a solvent process) or expellers (output from a pressing process) but publishes aggregated prices for "cakes" we assign meals/expellers similar values.

Table 6-7. Important allocation updates in Agri-footprint 7. *) Output value per mass has no consistent unit between processes. It might be for example price in USD/ton, price in EUR/ton but also relative values as communicated by industry experts when actual prices are confidential. Units are always consistent within the process to ensure correct allocation. [1)] USD/ton based on FAOSTAT 5-year average (2014-2018)

Process		Outputs	Amount	AFP 8	
			kg	Value/ton *	Economic allocation %
Palm fruit bunch crushing		Palm oil	200	960[1]	81.5%
		Palm kernel	55	790[1]	18.5%
Groundnut crushing	solvent	Crude groundnut oil	360	1351[1]	79.4%
		Groundnut meal	379	333[1]	20.6%
Linseed crushing	solvent	Crude linseed oil	350	1210[1]	51.8%
		Linseed meal	640	616[1]	48.2%
Linseed crushing	pressing	Crude linseed oil	270	1210[1]	42.6%
		Linseed expeller	715	616[1]	57.4%
Maize wet milling, germ oil production	pressing	Crude maize germ oil	330	1091[1]	66.4%
		Maize germ meal expeller	655	278[1]	33.6%
Maize wet milling, germ oil production	solvent	Crude maize germ oil	430	1091[1]	75.3%

		Maize germ meal extracted	555	278[1]	24.7%
Palm kernel crushing		Crude palm kernel oil	470	1090[1]	89.3%
		Palm kernel expeller	530	116[1]	10.7%
Rapeseed crushing	pressing	Crude rapeseed oil	310	897[1]	59.8%
		Rapeseed expeller	680	275[1]	40.2%
Rapeseed crushing (EU)	solvent	Crude rapeseed oil	413.2	897[1]	70.1%
		Rapeseed meal	574.4	275[1]	29.9%
Rapeseed crushing (non-EU)	Solvent	Crude rapeseed oil	428	897[1]	73.0%
		Rapeseed meal	518	275[1]	27.0%
Rice bran oil production		Crude rice bran oil	140	1564[1]	34.6%
		Rice bran meal	860	480[1]	65.4%
Soybean crushing	pressing	Crude soybean oil	140	776[1]	24.7%
		Soybean expeller	830	400[1]	75.3%
Soybean crushing	solvent, with protein-concentrate	Crude soybean oil	180	776[1]	11.3%
		Soybean hull	74	125	0.7%
		Soybean molasses	290	35	0.8%
		Soybean protein-concentrate	540	2000	87.2%

Soybean crushing (EU)	solvent	Crude soybean oil	192.31	776[1]	32.2%
		Soybean meal	784.62	400[1]	67.8%
Soybean crushing (non-EU)	solvent	Crude soybean oil	190	776[1]	33.6%
		Soybean meal	706	400[1]	64.3%
		Soybean hull	74	125	2.1%
Sunflower seed crushing	pressing	Crude sunflower oil	220	866[1]	68.8%
		Sunflower seed expelled dehulled	415	209[1]	31.2%
		Sunflower hull	350	0	0.0%
Sunflower seed crushing	solvent	Crude sunflower oil	285	866[1]	77.2%
		Sunflower seed meal	350	209[1]	22.8%
		Sunflower hull	350	0	0.0%
Maize dry milling		Maize flour	595	412[1]	75.1%
		Maize middlings	405	200	24.9%

6.4.2 Oil refining

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

Table 6-8: Process in- and outputs of oil refining

	Sunflower oil	Rapeseed oil	Soybean oil	Palm oil	Palm kernel oil
Literature source	(Nilsson et al., 2010)	(Schneider & Finkbeiner, 2013)			(Nilsson et al., 2010)
Inputs					

Crude oil	kg	1,046.46	1,032	1,038	1,080	1,068.8
Water	kg	0	500	540	130	0
Bleaching earth	kg	3.03	4.0	5.4	12	4.3
Phosphoric acid (85%)	kg	0	0.7	1.0	0.85	0
Sulfuric acid (96%)	kg	0	2.0	2.0	0	0
Nitrogen (N_2)	kg	0	0.5	0	1.5	0
Activated carbon	kg	5.05	0.2	0.2	0	0
Sodium hydroxide	kg	0	3.0	2.8	0	0
Steam	kg	266	170	225	115	214.67
Electricity	kWh	54.8	27	40	29	48.07
Diesel fuel	kg	8.02	0	0	0	8.53
Outputs						
Refined oil	kg	1,000	1,000	1,000	1,000	1,000
By-products	kg	37.95	20	23	70	67.2
Waste						
Waste water	l	0	522	446	154	0

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

Table 6-9: Average process in and outputs of oil refining of maize germ oil, rice bran oil, coconut oil, linseed oil.

Inputs		
Crude oil	kg	1,039
Water	kg	347
Bleaching earth	kg	4.14
Phosphoric acid (85%)	kg	0.57
Sulfuric acid (96%)	kg	1.33
Nitrogen (N_2)	kg	0.17
Activated carbon	kg	1.81
Sodium hydroxide	kg	1.93
Steam	kg	220
Electricity	kWh	40.6
Diesel fuel	kg	2.67
Outputs		
Refined oil	kg	1,000
By-products	kg	27.0

Table 6-10 presents the key parameters that were used to determine the allocation fractions for the co-products of rapeseed, soybean and palm oil refining. For the other refined oils, it is assumed that the by-products have the same properties as rapeseed and soybean oil (i.e. same LHV and average of the economic values for co-products) see Table 6-11.

Table 6-10: Key parameters required for mass, energy and economic allocation.

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

Table 6-11: Estimated key parameters required for mass, energy and economic allocation for other refined oils and soap stock.

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

6.5 Pulse products

Broad beans crushing into meal and hull was based on (Broekema & Smale, 2011). Broad beans, lupins, pea and soybean processing into protein-concentrate and protein-isolate was based on the internship report by (van Veghel, 2017) at Blonk Consultants. The LCAs are based on literature and company communication. Table 6-12 shows the dry matter (DM) content, prices and gross energy (GE) content used for allocation purposes for all pulse outputs.

Table 6-12: Key parameters for mass, energy and economic allocation.

Output	DM content (g/kg)	GE content (MJ/kg)	Price (€/ton)
Broad bean, meal	900	18.0	550
Broad bean, hulls	900	9.2	130

Lupins fibre	600	9	495
Lupins hull	960	10.6	285
Lupins okara	410	3	140
Lupins protein slurry	35	0.3	489
Lupins oil	100	39.1	759
Lupins protein-concentrate	900	19.7	1600
Lupins protein-isolate	900	19.7	2785
Pea wet animal feed	220	5.5	46
Pea starch-concentrate	905	16.3	495
Pea slurry	330	3	35
Pea protein-isolate	900	17	3500
Pea protein-concentrate	905	19.7	1600
Pea starch slurry	400	3	274
Soybean okara	410	3	140
Soybean slurry	110	0.3	372
Soybean fines	910	9	313
Soybean molasses	600	11.2	35
Soybean protein-concentrate	930	19.7	2000
Soybean protein-isolate	950	19.7	4350

6.5.1 Pulse protein-concentrates

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

During the production of the protein concentrate for lupins, other products are also created, the lupins hulls, lupins fibre and Biowaste as a residue are part of the processes (Figure 14), in the case of soybean protein-concentrate production, there are also products created, these are soybean fines and soybean molasses (Figure 15). For pea protein-concentrate, as a part of the production process, the pea starch and biowaste are created (Figure 16). The allocation of these products is in Table 6-7 and the parameters of these products are in Table 6-12.

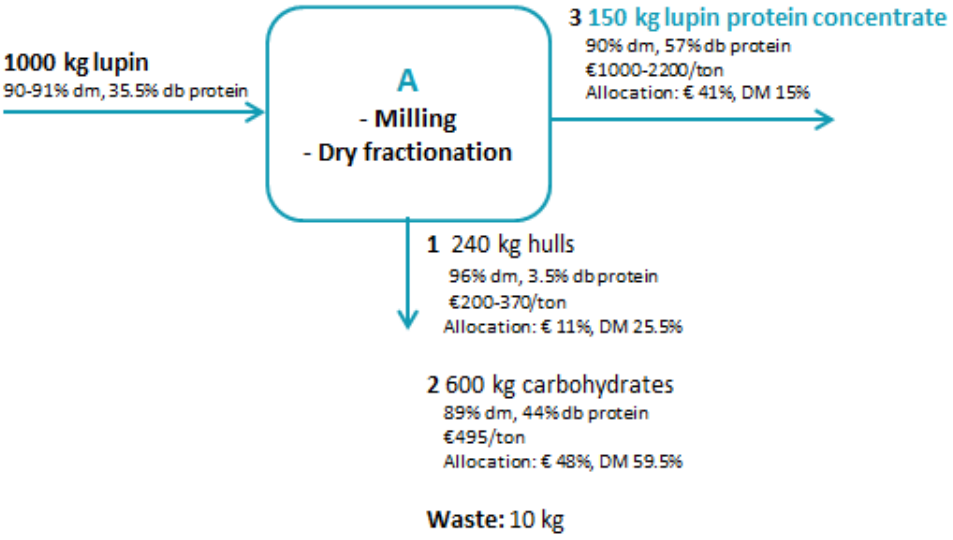


Figure 14: Lupin protein-concentrate production process (Van Veghel, 2017).

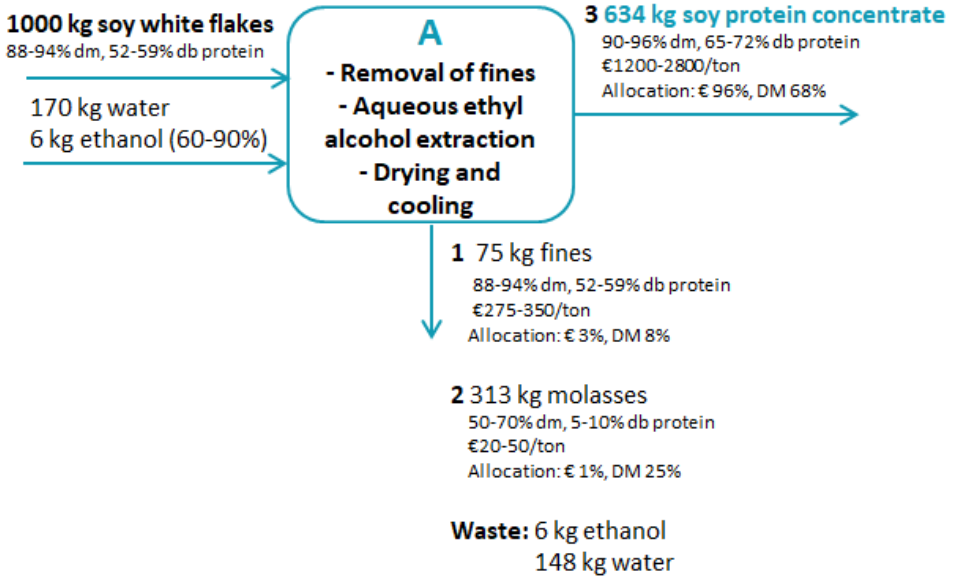


Figure 15: Soy protein-concentrate production process (Van Veghel, 2017).

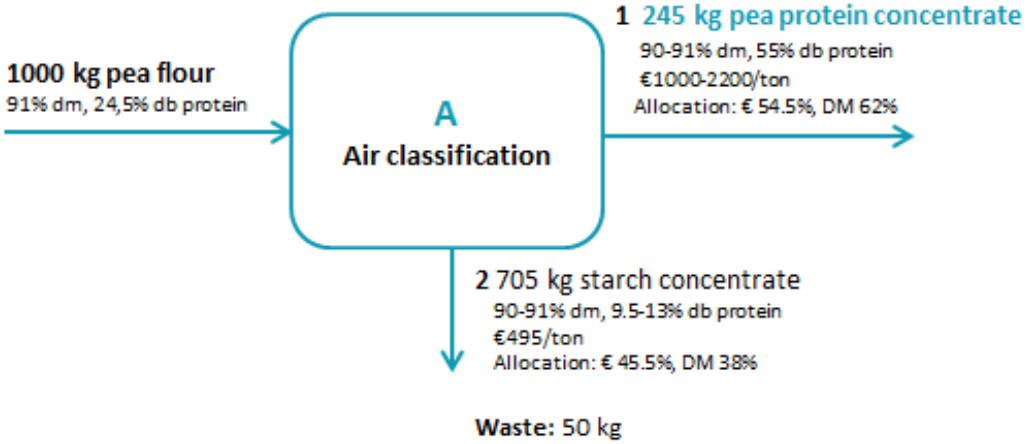


Figure 16: Pea protein-concentrate production process (Van Veghel, 2017).

6.5.2 Pulse protein isolates

Isolates are produced through a two step process. Soybean isolate processing is a wet treatment on soybean meal, also called white flakes (Figure 17). Through acid and basic treatment, the proteins are separated. The second step is spray drying of the protein slurry. Same process is considered for lupin protein-isolate (Figure 18).

Production of pea protein isolate is shown in Figure 19 and occurred through separation of starch by hydrocyclones, followed by separation of fibres by a decanter centrifuge. After which precipitation of the soluble proteins occurred upon addition of phosphoric acid. These precipitated proteins were neutralized by sodium hydroxide and then spray dried. In Agri-footprint, a direct input of dried peas has been assumed, since no data was available on pea milling into flour.

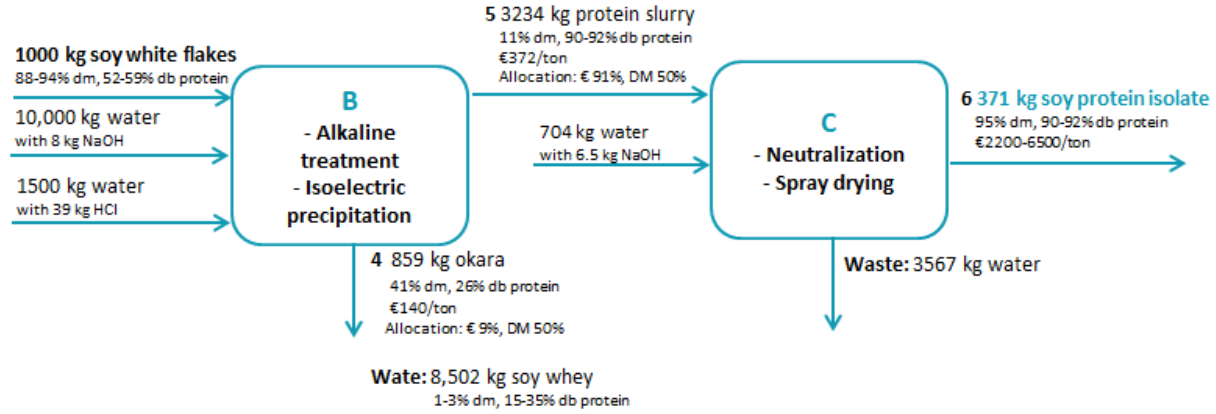


Figure 17: Soy protein-isolate production process (Van Veghel, 2017).

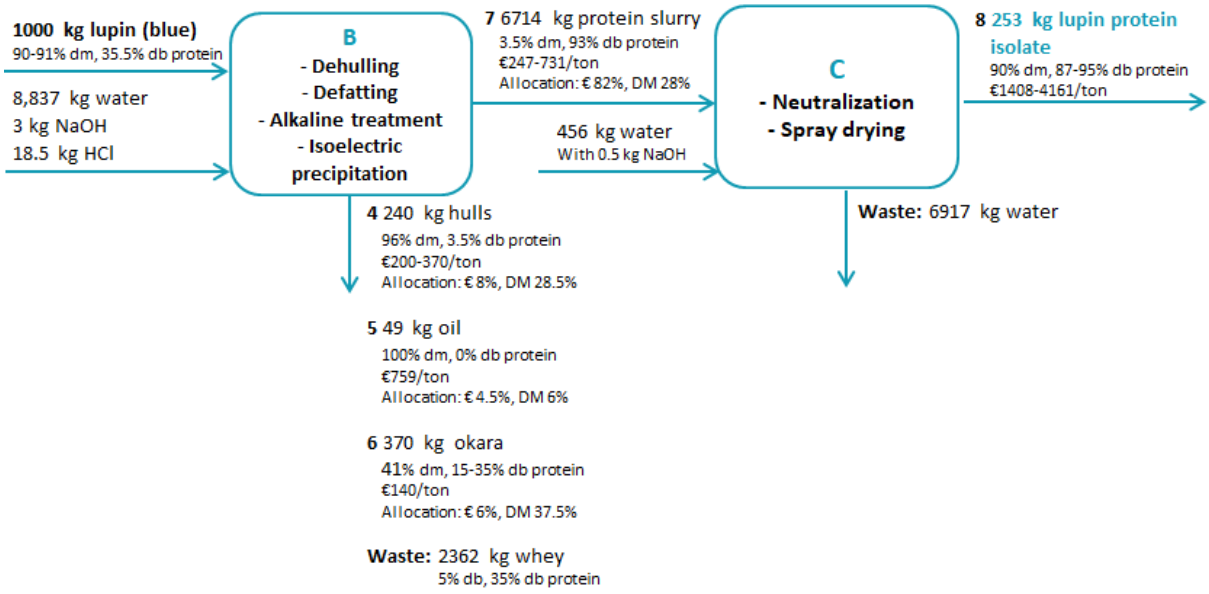


Figure 18: Lupin protein-isolate production process (Van Veghel, 2017).

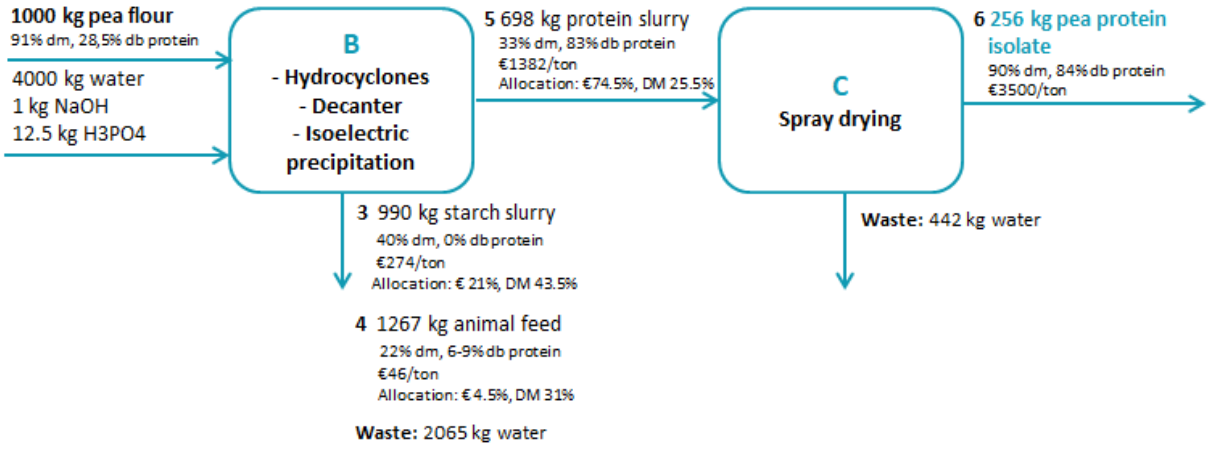


Figure 19: Pea protein-isolate production process (Van Veghel, 2017).

6.6 Roots & tuber products

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

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

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

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

19.1 m^3 of wastewater is generated to produce 1 ton of tapioca starch output. This is identical to 454 kg of wastewater per ton of cassava root input. The amount of peels is subtracted (454 kg – 90 kg) from the wastewater because peels are used as feed and do not end up in the wastewater (Chavalparit & Ongwandee, 2009). The pomace will end up in the wastewater, so the wastewater amount increased (454 kg + 150 kg).

6.7 Sugar products

6.7.1 Sugar from sugar beet

In 2012, the European Association of Sugar Producers (CEFS) published a report on the carbon footprint of EU sugar from sugar beets (Klenk et al., 2012). It is a detailed publication,

containing the mass balance as well as energy requirements with a division between the sugar factory and the pulp drier. Average EU beet sugar factory emissions were calculated based on an EU-wide study conducted by ENTEC for the CEFS in 2010. The data covered the period 2005–2008. Sugar beet molasses, lime fertilizer and wet sugar beet pulp are co-products of the “sugar from sugar beet” production process.

6.7.2 Sugar from sugar cane

Several inputs are necessary during sugar cane processing. As (Renouf et al., 2010) has the most transparent references this is the main data provider and the report of (ETPi, 2011) was used when the required data was not available in the article of Renouf et al. Sugar cane molasses is a co-product of the “sugar from sugar cane” production process.

In the Feedprint data, the combustion of bagasse during sugar cane processing was not modelled (as the focus of the Feedprint project was on fossil carbon emissions). However, the emissions from bagasse combustion are included in Agri-footprint. When one ton of sugarcane is processed, 280 kg of bagasse is created, which is combusted in the processing plant to provide heat and electricity. It is assumed that all the energy is used internally, and none is exported to a (heat or electricity) grid. The emissions are calculated from the emissions listed in (Renouf et al., 2010) and by the Australian (National Greenhouse Gas Inventory Committee, 2007) and are provided in Table 6-13. Although it is possible for sugar mills to produce electricity as surplus for the market, there is no data on how common this practice is, so the assumption was made that no surplus electricity is delivered to the market.

Table 6-13: Gas emissions from combustion of 280 kg of bagasse ‘as is’ (wet mass).

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

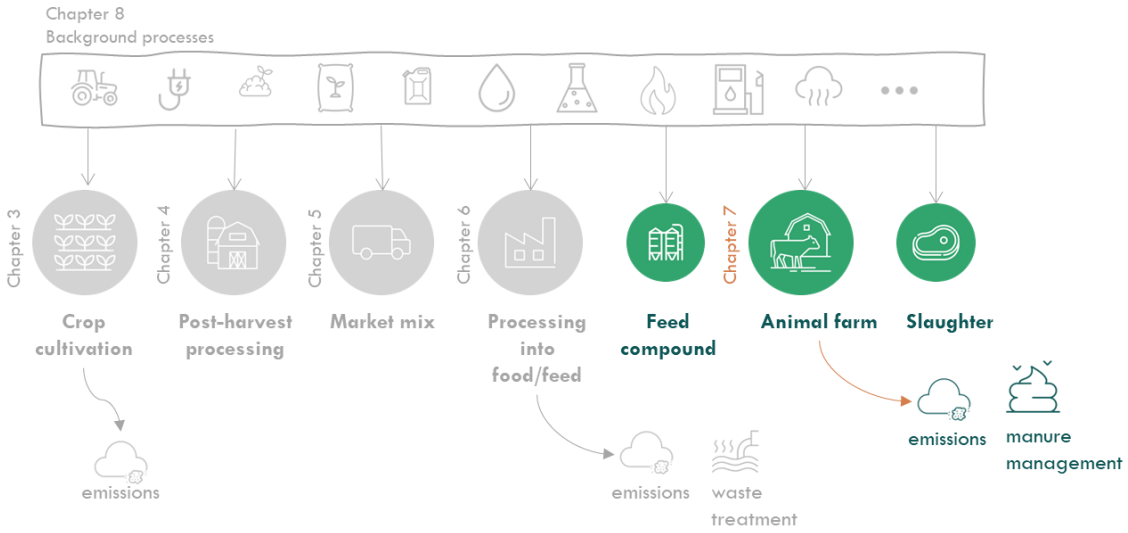
(Renouf et al., 2010) mention that the water evaporated from the cane is enough for what is needed. COD is described as 23 kg per 100 ton cane input. (European Commission, 2006) only notes that the water consumption is 'less' than sugar beet.

6.8 Fruits and vegetables products

In Agri-footprint 8, we added a large number of fruits and vegetables LCI’s to the catalogue, compared to the previous version of the database. For the majority of fruits and vegetables, the final deliverable product is without post-process transformations. The full list of fruits and vegetables from the crop model that are processed: as follows, with their products:

- Coconuts: husks, coconut de-husked, copra meal, coconut oil, soap stock (coconut), and refined coconut oil.

7. Animal Farm Systems



Please note that all farms here described are single enterprise, 'conventional' animal production systems. High welfare and organic systems are not included.

Table 7-1: Summary of animal production systems/country combinations included in Agri-footprint 6.

Animal production system	Country/regions included	Comment
Dairy farm system	BE, BR, DE, DK, ES, FR, GB, IE, IT, NL, NZ, PL, RER, US	RER as production mix
Beef system	BE, DE, FR, IE, IT	
Pig system	BE, BR, DE, DK, ES, FR, GB, NL, RER, RNA	Including breeding and fattening
Broiler system	BR, CN, FR, JP, NL, RER, TH, US	Including parent rearing, one day-chicken breeding and broiler fattening
Layer system	NL, RER, RNA	Including pullet rearing and egg production

7.1 Dairy Farm Systems

Raw milk production has been modelled for different countries worldwide, modelling typical conventional farm systems. Countries in scope are Belgium, Brazil, Germany, Denmark, Spain, France, Great Britain, Ireland, Italy, the Netherlands, New Zealand, Poland and the United States. For Europe, a production mix of various European countries is compiled.

In the case of Belgium, the dataset is developed based on Flanders statistical data, therefore excluding the Wallonia productions. The distinction between Flanders and Wallonia is necessary due to the large differences in farm management practices (e.g., grazing, milk yield) and legal framework between these two regions in Belgium. The share of Flanders in BE dairy production is around 70%.

In the case of USA, the dataset is based on California data, since this is of higher availability compared to data at overall country level. The share of California in US dairy production is around 35%.

The datasets were originally developed during the Environmental Footprint (EF 3.0) (European Commission, 2022) agri-food database development (2021), and most of the datasets were developed in partnership with the European Dairy Association (EDA). This was done through involving country specific experts reviewing datapoints and providing alternative sources to improve the representativeness of the dataset.

Dairy farms are mixed, meaning that they have animal (housing system) and cultivation systems. Most of the farms have been normalized to a 100 dairy cow herd.

Raw milk is the main product that is produced on dairy farms. In addition, calves are produced (kept partly for herd replacement and partly sold to the veal industry), and unproductive cows are sent to slaughter. Also, in some countries it is typical to sell heifers and calves after being reared.

Table 7-2: Data sources for dairy farm parameters

Parameter	Country	Source
Milk yield and characteristics	BE, DE, GB, PL	(UNFCCC, 2021)
	BR	(Maciel, 2019)
	DK	(SEGES, 2021)
	ES	(CONAFE, 2021)
	FR	(Thomas & Bourrigan, 2019)
	IE	(CSO, 2021)
	IT	(Eurostat, 2021c; UNFCCC, 2021)
	NL	(Wageningen UR, 2021a)
	NZ	(LIC, 2021; NZ Dairy, 2019)
	US	(CDFA, 2016; UNFCCC, 2021)
Animal mortality	BE	(FAO, 2018c; Landbouwmonitoringnetwerk (LMN), 2019)
	BR	(Maciel, 2019)
	DE, ES, GB, IT, PL, US	(FAO, 2018c)
	DK	(FAO, 2018c; SEGES, 2021)
	IE, NL, FR	(Wageningen UR, 2021b)
	NZ	(FAO, 2018c; Harris, 1989)
Herd composition and sold animals	BE	(Van Mierlo & Bracequené, 2020)
	BR	(Maciel, 2019)
	DE, GB, IT, PL	(FAO, 2018c; UNFCCC, 2021)
	DK	(Mogensen et al., 2015; SEGES, 2021; UNFCCC, 2021)
	ES	(MAPA, 2020)

	FR	(Thomas & Bourrigan, 2019)
	IE	(Dillon et al., 2021; ICBF, 2021)
	NL	(Wageningen UR, 2021a)
	NZ	(LIC, 2021; NZ Dairy, 2019)
	US	(Thoma et al., 2013)
Animal weights	BE, BR, DE, DK, ES, FR, GB, IE, IT, NL, NZ, PL, US	Kringloopwijzer & expert knowledge
Feed intakes	BE	(Landbouwmonitoringnetwerk (LMN), 2019; Leip, 2017)
	BR	(Maciel, 2019)
	DE, DK, FR, GB, IT, NL, PL	(Leip, 2017)
	ES	MAPA (2019)
	IE	(Dillon et al., 2021)
	NZ	(DairyNZ, 2016)
	US	(Thoma et al., 2013)
Bedding materials	BE, DE, FR, GB, NL, PL, US	(Wageningen UR, 2021b)
	DK	(SEGES, 2021)
	ES	(MAPA, 2020)
	IE	(Dillon et al., 2021)
	IT	(Famiglietti et al., 2018)
Water use	BE	(Van Mierlo & Bracequené, 2020)
	BR	(Maciel, 2019)
	DE, DK, ES, GB, NL, NZ, PL, US	(Wageningen UR, 2021b)
	FR	(Menard et al., 2012)
	IE	(Murphy et al., 2017)
	IT	(Famiglietti et al., 2018)
Energy use	BE	(Van Mierlo & Bracequené, 2020)
	BR	(Maciel, 2019)
	DE, DK, ES, FR, GB, NL, PL	(Wageningen UR, 2021b)
	IE	(Upton et al., 2013)
	IT	(Famiglietti et al., 2018)

	NZ	(Chobtang et al., 2016; Stats NZ, 2021)
	US	(Thoma et al., 2012)
Time spent on pasture and manure management system	BE, DE, DK, ES, GB, IT, NZ, PL, US	(UNFCCC, 2023) & (IPCC, 2019a)
	BR	(Maciel, 2019) & (IPCC, 2019a)) & (UNFCC, 2023)
	FR	(IDELE, 2021; INOSYS Réseaux d'Elevage, 2021) & (IPCC, 2019a)) & (UNFCC, 2023)
	IE	Expert knowledge & (IPCC, 2019a) & (UNFCC, 2023)
	NL	(CBS (Centraal Bureau voor de Statistiek), 2019); UNFCCC, 2021) & (IPCC, 2019a). & (UNFCC, 2023)
Compound feed formulation	BE, DE, FR, GB, IE, IT, PL	(Leip, 2017)
	BR	(Guimarães Júnior et al., 2007; Salman et al., 2011)
	DK	(Leip, 2017; N. I. Nielsen, 2021)
	ES	(MAPA, 2020)
	NL	(Personal Communication, 2013)
	NZ	(Ledgard et al., 2020)
	US	(Thoma et al., 2013)
Climate types	BE, DE, DK, ES, FR, GB, IE, IT, NL, PL	(European Commission, 2024)
	BR, NZ, US	IPCC 2019a

The herd at the farm consists of dairy cows, and replacement animals (calves < 1 year, calves 1-2 years and heifers). In most cases, for comparability or data gaps, 100 dairy cows were used as reference values, not representative of the actual typical country specific herd size. Heifers are defined as animals that are older than 2 years, but before their first calving. Male animals are assumed to be completely sold after birth, and the presence of bulls for reproduction is neglected in the system. The amount of the replacement animals is dependent on the dairy cow's replacement rates, various animal mortalities, age of calving and age of slaughtering.

Table 7-3: Herd size at various country dairy farms, and other herd dynamics parameters.

Herd size and dynamics	BE	BR	DE	DK	ES	FR	GB	IE	IT	NL	NZ	PL	US
Female Calves < 1 yr (#)	35.9	49	35.8	54.0	29.5	32.9	38	17.8	35.3	29.1	24	35.3	23
Female Calves 1-2 yr (#)	33.7	48	33.6	50.7	27.7	31.1	35	17.1	33.1	25	24	33.2	21
Heifers (#)	9.9	0	10.6	12.2	2.3	15	10	3.4	11.0	3.4	0	10	5
Dairy cows (#)	100	120	100	100	100	100	100	82	100	102	100	100	51

Dairy cows replacement rate (%)	33	17	33	35	27	30	32	21	32	28	22	32	31
Dairy cows mortality (%)	4.4	1.8	4.0	5.4	4.0	2.0	4.0	2.0	4.0	2.0	1.2	4.0	4.0
Dairy cows average weight (kg)	600	400	650	653	675	700	608	535	603	650	449	540	680
Heifer mortality (%)	4.0	-	4.0	4.0	4.0	2.0	4.0	2.0	4.0	2.0	-	4.0	4.0
Heifers average weight (kg)	459	-	496	503	532	525	462	415	459	508	-	411	523
Calves 1-2 yr mortality (%)	4.0	1.0	4.0	4.0	4.0	3.0	4.0	2.0	4.0	2.0	2.0	4.0	1.6
Female Calves 1-2 yr average weight (kg)	369	325	399	405	431	420	371	334	369	410	292	330	421
Calves <1 yr mortality (%)	8.0	3.0	8.0	8.0	8.0	8.0	8.0	5.0	8.0	3.0	6.0	8.0	6.4
Female Calves <1 yr average weight (kg)	171	143	185	186	192	74	174	152	172	185	128	154	194
Age at first calving (years)	2.3	2.0	2.3	2.2	2.1	2.5	2.0	2.2	2.3	2.1	2.0	2.4	2.3

Dairy farms are a multi-output systems, where together with milk, sold animals are also leaving the farm. In all cases, part of the dairy cow herd is replaced each year. These cows that reached the end of their productive life are typically culled and sent directly to the slaughterhouse. Most of male calves and some of the female calves (not needed for replacement) are sold for further rearing or sometimes directly for slaughtering. In some countries, it is also typical to sell some of the grown animals (e.g., grown calves or heifers).

For allocation purposes, the dry matter, energy content and prices of the various co-products need to be defined. These values are based on the Dutch situation and are not country specific. The prices in particular are based on a 5-year average from BINternet (2007-2011) (Wageningen UR, 2015b). FPMC milk is considered to have a 13.4% dry matter, an energy content of 3.34 MJ/kg and a value of €0.339 per liter. Liveweight is considered to have a 42.6% dry matter, an energy content of 11.28 MJ/kg liveweight. Prices for culled cows and sold calf are €0.888 and €3.182 per kg liveweight, respectively. The price for sold heifer and calves 1-2 years has been derived as an average of the two previous datapoints (€2.035 per kg liveweight).

Table 7-4: Milk output (and its characteristics) and sold animals at various country dairy farms.

Outputs and characteristics	BE	BR	DE	DK	ES	FR	GB	IE	IT	NL	NZ	PL	US
Milk (kg/dairy cow per year)	9097	4869	7748	10068	8310	7373	8071	5443	7329	8652	4359	5511	10418
Milk protein content (%)	3.7	3.2	3.4	3.5	3.2	3.2	3.3	3.5	3.5	3.6	3.9	3.2	3.3
Milk Fat content (%)	4.5	3.9	4.1	4.3	4.0	4.0	4.0	4.1	4.0	4.4	5.0	4.1	4.0
FPCM Milk (kg/dairy cow)	10048	4782	7902	10593	7990	7315	8070	5620	7442	9277	5096	5535	10323
Culled dairy cows (#)	28.3	20	28.5	29.5	30.7	33	28	16.9	28	26	21	28	31

Culled dairy cows average weight (kg)	600	500	650	653	675	700	608	535	603	650	449	540	680
Sold Calves (after birth) (#)	46.6	50	47.8	26.8	45.3	46.7	38.6	57.2	49.2	66.5	71	38.6	64
Sold Calves (after birth) average weight (kg)	42.0	35	45.5	45.7	47.3	49.0	42.6	37.5	42.2	45.5	31.4	37.8	47.6
Sold Heifers	-	-	-	14.3	-	-	-	-	-	-	-	-	-
Sold Heifers average weight (kg)	-	-	-	522	-	-	-	-	-	-	-	-	-

Energy consumption at a dairy farm consists of electricity, diesel, and natural gas, see Table 7-5 for the consumption of electricity and natural gas. The diesel consumption for land management is incorporated in the cultivation and production of roughage. Also, water is used at the dairy farm, both as drinking water and cleaning water. The source of drinking water is commonly groundwater. Irrigation water is considered in the pasture and roughages cultivation inventory. Bedding materials, in the form of wheat straw and saw dust, are considered in dairy cows' housing.

Table 7-5: Energy consumption and water use at various country dairy farms.

Country	Electricity	Natural Gas	Fuel	Water	Wheat straw	Saw dust
	MJ/dairy cow/year			m^3/dairy cow/year	kg/dairy cow/year	
BE	1364	-	1.3	40.6	55	125
BR	1387	-	-	83.6	-	-
DE	1432	417	-	41.8	55	125
DK	1480	-	-	41.8	44	6.25
ES	1480	-	-	41.8	730	1825
FR	1362	-	-	50.5	55	125
GB	1480	-	-	41.8	55	125
IE	1630	-	1068	36.0	50	-
IT	1963	-	-	47.6	675.1	-
NL	1599	408	-	41.8	55	125
NZ	285	10	-	41.8	55	125
PL	1480	-	-	41.8	55	125
US	2175	-	-	41.8	250	125

The feed intakes of the various countries dairy farms are displayed in Table 7-6. The various animals ration consists of (1) concentrates, also called compound feeds, (2) fresh grass, which animals eat in pastures, (3) farm grown feed, that mostly consists of grass silage and maize silage, and (4) single ingredients, like for instance straw. For calves, the feed ration depends on their age. When calves are very young and stabled, they are usually fed with raw milk

directly from the cows. This milk is produced by the cows but does not end up in the milk tank. Because the dairy farm is modelled as one animal system which produces calves, milk and meat, the milk which is fed to the calves is accounted for in this manner. The rest of the ration consists of concentrates, grass silage and maize silage. When calves are older, they spend relatively more time in the pasture where they eat mainly grass. The heifers were assumed to be fed the same ration as the female calves 1-2 years of age.

The overall diet fed to the various animal types is assumed to have 70% digestibility (% of GE) with the exception of calves < 1 year, for which an 80% (% of GE) is assumed. These were based on (IPCC, 2006a). Based on the same source, we assumed the GE content of the overall animals' diet to be 18.45 MJ/kg DM. The natural detergent fiber content of the dairy cow's single ingredients was based on Feedipedia.

For the United States system, the feed intakes are simplified. Due to the aggregated form in which the data on feed intake was available, the feed fed to the various replacement animals is fully allocated to heifers. This results in an unbalanced hotspot analysis. Hence, the feed intake of calves < 1 yr & calves 1-2 yr is not illustrated separately for the United States.

Table 7-6: Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' dairy farms per various feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet.

Type of animal	Compound feeds intake	Fresh grass intake	Farm grown feed intake	Single ingredients intake	Overall diet dry matter content	Overall diet crude protein content
BE	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	458	10	936	-	42.4	12.1
Calves 1-2 yr	377	1743	921	-	22.2	20.8
Dairy cows	1441	1375	3460	225	32.7	18.1
Heifers	377	1743	921	-	22.2	20.8
BR	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	659	-	-	-	90.2	31.2
Calves 1-2 yr	659	1120	2424	-	27.5	24.1
Dairy cows	2635	455	4088	-	38.7	25.8
DE	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	24	952	384	-	18.8	20.0
Calves 1-2 yr	73	2897	1119	-	19.0	20.6
Dairy cows	781	587	5379	430	31.3	14.8
Heifers	73	2897	1119	-	19.0	20.6
DK	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	67	6	2029	139	47.1	18.3
Calves 1-2 yr	279	1807	956	538	24.2	18.5
Dairy cows	2480	29	4049	736	52.4	16.7
Heifers	279	1807	956	538	24.2	18.5
ES	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	522	265	175	-	35.3	27.1
Calves 1-2 yr	233	1215	2125	-	27.4	26.8
Dairy cows	2093	2269	1730	-	27.7	26.8
Heifers	233	1215	2125	-	27.4	26.8
FR	DMI, kg/animal/year				DM, %	CP, % of DM

Calves < 1 yr	602	55	447	9	41.4	17.1
Calves 1-2 yr	166	1970	2293	39	25.4	20.6
Dairy cows	1885	634	4850	557	41.2	16.8
Heifers	166	1970	2293	39	25.4	20.6
GB	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	101	1070	199	-	18.8	22.0
Calves 1-2 yr	391	3213	262	-	18.4	23.4
Dairy cows	1457	2810	4169	205	30.4	20.3
Heifers	391	3213	262	-	18.4	23.4
IE	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	333	487	320	27	23.9	16.2
Calves 1-2 yr	182	1339	814	-	19.2	16.2
Dairy cows	1026	2797	1144	23	21.1	16.3
Heifers	182	1339	814	-	19.2	16.2
IT	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	779	108	568	9	65.1	22.1
Calves 1-2 yr	493	1423	2228	40	28.7	22.1
Dairy cows	1320	1108	4850	257	39.4	20.3
Heifers	493	1423	2228	40	28.7	22.1
NL	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	173	563	702	-	26.5	20.9
Calves 1-2 yr	257	1729	598	-	20.9	21.9
Dairy cows	1732	1906	2825	69	30.3	21.5
Heifers	257	1729	598	-	20.9	21.9
NZ	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	-	1048	-	-	16.0	23.1
Calves 1-2 yr	-	1968	-	-	16.0	23.1
Dairy cows	668	4040	222	-	18.4	21.2
PL	DMI, kg/animal/year				DM, %	CP, % of DM
Calves < 1 yr	893	47	104	127	63.1	14.5
Calves 1-2 yr	479	2187	827	669	24.6	20.3
Dairy cows	2842	762	1034	604	42.6	15.0
Heifers	479	2187	827	669	24.6	20.3
US	DMI, kg/animal/year				DM, %	CP, % of DM
Dairy cows	3226	3018	992	571	48.4	26.3
Heifers	6216	10649	3557	2835	39.7	30.2

The feed material compositions of the daily ration have been mostly based on a model shared by (Leip, 2017), which were based on import/export feed ingredients statistics and allocation to various animal types. For the Netherlands, compound feeds have been based on the analysis of the yearly throughput of feed raw materials, specifically for dairy of Agrifirm - the market leader in animal feed production in the Netherlands (Personal Communication, 2013). For Spain the feed ration was based on MAPA (2019). A weighted average was calculated to make sure all regions were represented. Due to the large number of rations (animal and country specific), the exact composition has not been included in this documentation and can be found directly in the Unit LCI database.

The energy consumption for the manufacturing of compound feed is based on the Feedprint study (315 MJ of electricity and 135 MJ of natural gas). Transportation of compound feed to the animal farm is not included and will be implemented in future versions of the database.

Roughage is produced on dairy farms with a fraction of the manure which is excreted by the dairy cattle. These are in principle with the same methodology described previously for other types of cultivations.

Calculated emissions are CH_4 from enteric fermentation and various manure management related emissions: CH_4, N_2O direct and indirect, NH_3, NO_X, NMVOC and $PM_{2.5}$. Also, NMVOC emissions from silage feeding are included. All these emissions have been calculated with the Blonk Animal Life Cycle Engines (Blonk Consultants, 2020a, 2020c).

For each country specific dairy farm, animal-specific manure management shares have been considered (IPCC, 2019a; UNFCC 2023) accounting for the time share that animals spend outside in the pasture (Table 7-7). This affects the ratio of excretions dropped in the stable and on the pasture. Days spent on the pasture reflect full 24 hours spent outside. As mentioned in section 3.5, to avoid double counting, the emissions generated due to the manure excreted on pasture while animals are grazing (Percentage of time spent outside) are reported in the respective the background “Grass production process" and not as direct emissions from the system.

Table 7-7: Manure management system mix and time spend outside for various countries dairy farms.

Type of animal	Calves < 1 yr	Calves 1-2 yr	Dairy cows	Heifers
BE	%	%	%	%
Percentage of time spent outside	6	6	14	0
Pit storage (6 months)	63.31	63.31	63.31	63.31
Solid storage	36.69	36.69	36.69	36.69
BR	%	%	%	
Percentage of time spent outside	0	50	50	-
Uncovered anaerobic lagoon	63.42	63.42	63.42	-
Solid storage	35.63	35.63	35.63	-
Anaerobic digester; high leakage, low quality technology, low quality gastight storage technology	0.95	0.95	0.95	-
DE	%	%	%	%
Percentage of time spent outside	0	20	11	20
Solid storage	8.29	8.29	8.29	8.29
Pit storage (4 months)	66.56	66.56	66.56	66.56
Anaerobic digester; low leakage, high quality industrial technology, open	25.15	25.15	25.15	25.15
DK	%	%	%	%
Percentage of time spent outside	5	36	5	36
Pit storage (4 months)	70.65	70.65	70.65	70.65
Solid storage	0.76	0.76	0.76	0.76
Anaerobic digester; high leakage, low quality technology, high quality gastight storage technology	28.59	28.59	28.59	28.59
ES	%	%	%	%
Percentage of time spent outside	63	63	0	63

Uncovered anaerobic lagoon	6.42	6.42	6.42	6.42
Solid storage	42.46	42.46	42.46	42.46
Pit storage (1 month)	51.12	51.12	51.12	51.12
GB	%	%	%	%
Percentage of time spent outside	54	71	21	71
Pit storage (4 months)	76.89	76.89	76.89	76.89
Daily spread	9.85	9.85	9.85	9.85
Solid storage	10.95	10.95	10.95	10.95
Anaerobic digester; low leakage, low quality technology, open storage	2.31	2.31	2.31	2.31
FR	%	%	%	%
Percentage of time spent outside	30	55	39	55
Solid storage	62.60	62.60	62.60	62.60
Liquid/slurry with natural crust (4	31.30	31.30	31.30	31.30
Anaerobic digester; High leakage, low quality technology, high quality gastight storage technology	6.10	6.10	6.10	6.10
IE	%	%	%	%
Percentage of time spent outside	39	58	70	65
Pit storage (6 months)	100.00	100.00	100.00	100.00
IT	%	%	%	%
Percentage of time spent outside	5	5	5	5
Solid storage	32.60	32.60	32.60	32.60
Pit storage (3 months)	45.14	45.14	45.14	45.14
Anaerobic digester; Low leakage, High quality industrial technology, low quality gastight storage	22.26	22.26	22.26	22.26
NL	%	%	%	%
Percentage of time spent outside	3	8	12	8
Pit storage (4 months)	85.23	85.23	95.16	85.23
Solid storage	13.14	13.14	1.92	13.14
Anaerobic digester; Low leakage, High quality industrial technology, open storage	1.63	1.63	2.86	1.63
NZ	%	%	%	
Percentage of time spent outside	100	100	92	-
Uncovered anaerobic lagoon	100	100	100	-
PL	%	%	%	%
Percentage of time spent outside	12	12	10	12
Solid storage	88.26	88.26	88.26	88.26
Pit storage (4 months)	11.74	11.74	11.74	11.74
US	%	%	%	%
Percentage of time spent outside	100	100	14	1.00
Percentage in feedlot	-	-	-	87.12
Uncovered anaerobic lagoon	-	-	44.34	-
Pit storage (6 months)	-	-	21.76	0.58
Daily spread	-	-	2.03	-
Solid storage	-	-	31.88	99.42

7.1.1 Limitations Dairy System

In the modelling approach, several choices were made which led to a small uncertainty. First, a few feed background processes and nutritional characteristics were missing. In those cases proxies were used:

- For Spain: maize from Italy was used
- For Belgium: fodder beet from the Netherlands was used
- For Ireland: maize from the Netherlands was used
- For the United States: the dry matter content of fresh grass was aligned with the other countries in scope.

Furthermore, water was modelled as tap water rather than surface water. For the conversion factor for dietary gross energy per kilogram of dry matter, the default value 18.45 from IPCC (2019) was used. At last, the crude protein content and dry matter content of the Dutch feed composition was based on a different Dutch dairy feed composition as these were not delivered with the data. The missing feed background processes and replacement of surface water will have limited effect on the results. However, the crude protein and dry matter content of the Dutch feed composition will have a slightly larger effect on the results. Nevertheless, the contents corresponded largely with Dutch average values, meaning that the results will likely not differ as much. For the conversion factor for dietary gross energy is would be more accurate to determine the value on a single ingredient level. However, it is not expected that the average diet composition deviates largely from the IPCC suggested value; and thus, it will not have a significant effect on the results.

7.2 Beef System - Ireland

The Irish beef system is based on a study by (Casey & Holden, 2006). In the Irish beef system, beef is produced; it is not a dairy system. In this system, beef calves are primarily fed on grass in pasture for a large part of the year (214 days), and grass silage and compound feed in stable (151 days). Calves are weaned after approximately 6 months; therefore, no additional feed is required for the first 6 months. The feed regime is listed in Table 7-8, and a specification generic farming parameters in Table 7-8. Table 7-10 details the composition of the compound feed and a specification of the nutritional characteristics can be found in

Table 7-11. The meat calves are slaughtered after two years. However, the dietary requirements of cows that produce new calves are not mentioned in the study. Therefore, the feed ration intake of the calves in their second year has been used as a proxy for the feed intake of cows that are kept for breeding and herd replacement. The feed intake (

Table 7-9) from has been linearly scaled to the time spent in pasture and indoors (e.g. total time in pasture = 244 days, therefore grass intake in 30 days in year 1 is 30/244*12,355= 1,519 kg).

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

As mentioned in section 3.5, To avoid double counting, the emissions generated due to the manure excreted on pasture while animals are grazing are reported in the respective the background “Grass production process" and not as direct emissions from the system.

Table 7-8: Inventory for Irish beef production. Data on weights are based on by (Casey & Holden, 2006) and kringloopwijzer. bedding has been taken from kwantitatieve informatie veehouderij (kwin) 2022-2023, water, electricity, and diesel from (Casey & Holden, 2006), and the manure management system is based on (IPCC, 2019a; UNFCC 2023).

Farming practices	Unit	Quantity
Weight new-born calf	kg	44

Weight one-year old	kg	332.5
Weight two-year old / target live weight	kg	647
Weight heifer	kg	656
Weight cow	kg	665
Cows for slaughtering	#	3
2-year-old calves for slaughtering	#	15
Straw calf	kg	70.58
Straw one-year old	kg	69.42
Straw two-year old	kg	140
Straw heifer	kg	-
Straw cow	kg	200
Saw dust calf	kg	32.77
Saw dust one-year old	kg	32.23
Saw dust two-year old	kg	65
Saw dust heifer	kg	-
Saw dust cow	kg	100
Water farm	m^3	567.18
Electricity farm	kWh	3555
Diesel farm	MJ	68043.7
Manure management type	-	Pit 6 months

Table 7-9: Rations for cows and calves per animal for one year – based on (Casey & Holden, 2006).

Animal type	# on farm	Cow milk in pasture		Grazing in pasture		Grass silage and supplement in stable		
		Time (days)	Feed intake (kg milk)	Time (days)	Feed intake (kg grass)	Time (days)	Feed intake (kg grass silage)	Feed intake (kg supplement)
Calves age 0-1	18	184	3592.3	106.8	1,519	74.2	2,491.5	508
Calves age 1-2	18	-	-	214	10,796	151	2,491.5	508
Cows	20	-	-	214	10,796	151	2,491.5	508
Heifers	3	-	-	214	10,796	151	2,491.5	508

Table 7-10: Compound feed composition (Casey & Holden, 2006).

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

Table 7-11: Nutritional characteristics of the feed ration, based on IPCC (2019B) and Expert Knowledge.

Nutritional characteristic	Unit	Cow milk	Fresh grass	Grass silage	Supplement
Dry matter content	% of kg	13.00	16.00	47.00	93.20

Gross energy content	MJ/kg DM	23.00	18.45	18.45	18.45
Digestible energy content	% of GE	95.00	70.00	70.00	70.00
Urinary energy content	% of GE	4.00	4.00	4.00	4.00
Crude protein content	% of DM	23.08	23.00	23.05	17.35
Ash content	% DM	7.69	10.00	10.00	10.00
Phosphorus content	% DM	0.77	0.30	0.43	0.47
Protein content	%	1.62	-	-	-
Fat content	%	4.00	-	-	-

7.2.1 Limitations Beef System

The data to model the beef system is mostly based on (Casey & Holden, 2006). This means that the data originates from 2006, which means that it is outdated. Nevertheless, as there was no (new) data available, the same data was used for Agri-footprint 8.

Data on nutritional characteristics (including the conversion factor for dietary gross energy per kilogram of dry matter) and animal weights were not always present, meaning that assumptions were made. These assumptions were made with expert judgement.

7.3 Beef Systems – Rest of European countries

7.3.1 Data Sources and Methodological Approach

European beef production is characterized by a high degree of heterogeneity. Unlike other livestock sectors that are more uniform, beef production across Europe utilizes a wide variety of farming systems driven by local geography, climate, and available resources. Because of this vast diversity, it is important to note that the datasets modeled in this database represent specific, typified livestock systems per country, and do not represent statistical country averages.

To capture the technical parameters of these distinct systems, the primary data source used for the core modeling is a study originating from the European SustainBeef project (Balouzat et al., 2025). The primary objective of this publication was to evaluate the contribution of various European beef production systems to global food security, aiming to establish benchmarks for the sector and identify key drivers for improvement across diverse farm archetypes in major producing countries.

For the development of these specific LCA datasets, a selection of the case studies detailed in the publication was utilized. These selected archetypes provide robust, farm-level parameters, such as herd demographics, growth stages, specific feed rations, and land use—required to accurately model the distinct phases of European beef production.

7.3.2 Herd Dynamics and Outputs

The beef systems are modelled dynamically across their specific production stages (e.g., cow-calf breeding, finishing). The tables below outline the herd parameters for the breeding stages and the final mass balances of animals leaving the systems (annual sales).

Table 7-12: Cow-Calf Herd Parameters per System (Breeding Stage)

Parameter	BE-CC1	BE-CC2	FR-CC2 (CANT)	FR-CC1 (LIM)	BE-CCF	FR-CCF (LOR)
Number of cows	82	155	79	78	118	60
Weight newborn calves (kg)	46.00	46.00	35.00	43.50	46.00	49.00
Mortalities calves	2.16	6.20	3.00	4.00	3.45	4.00
Weight at mortality calves (kg)	144.83	173.00	159.40	170.62	173.00	173.37
Replacement number cows	34	68	10	15	39	14

Table 7-13: Annual Animal Sales and Output Weights per System

Parameter	BE-CC1	BE-CC2	FR-CC2	FR-CC1	BE-CCF	FR-CCF	IT-F900	IT-F226	GE.LS-F
Number male calves <1 yr leaving	31	92	35	36	0	0	0	0	0
Weight male calves <1 yr leaving	300 kg	300 kg	386.6 kg*	315 kg	-	-	-	-	-
Number female calves <1 yr leaving	4	0	20	3	0	0	0	0	0
Weight female calves <1 yr leaving	200 kg	-	331 kg*	280 kg	-	-	-	-	-
Number of store heifers	2	5	0	0	0	0	0	0	0
Weight of store heifers	400 kg	475 kg	-	-	-	-	-	-	-
Number of finished heifers	0	0	6	17	0	15	194	0	0
Weight of finished heifers	-	-	440 kg carc.	341.2 kg carc.*	-	380 kg carc.	687 kg	-	-
Number of store cows	34	68	0	0	0	0	0	0	0
Weight of store cows	750 kg	750 kg	-	-	-	-	-	-	-
Number of finished cows	0	0	9	14	42	13	0	0	0
Weight of finished cows	-	-	336.6 kg carc.*	400 kg carc.	740 kg	420 kg carc.	-	-	-
Number of bulls leaving	0	0	1	1	43	30	719	226	107
Weight of bulls leaving	-	-	550 kg carc.	620 kg carc.	600 kg	427.6 kg carc.*	687 kg	520 kg	685 kg

(Note: "kg" without "carc." denotes live weight. Carcass weights are explicitly labeled where applicable. An asterisk indicates a weighted average of multiple sub-groups.)

7.3.3 Feed Regimes and Nutrition

The feed intake and nutritional regimes for the various animal categories were modeled using a combination of the primary case study data, ingredient-specific nutritional profiles, and targeted energy balance calculations.

Feed Quantities and Fresh Grass Intake Estimation

For known feedstuffs (such as compound feeds, grass silage, maize silage, hay, straw, and grains), feed quantities are directly defined per system and animal stage based on case study data. Their energy contributions are evaluated using ingredient-specific nutritional characteristics. For suckling calves, the volume of milk consumed from mother cows is set to a default baseline value, which is fully internalized within the cow-calf system boundaries.

Because primary data regarding fresh grass consumption during pasture grazing is rarely measured directly on farms, the feed intake estimation model (aligned with IPCC 2019b) is applied **exclusively to estimate fresh grass intake**.

The fresh grass intake is estimated via an energy deficit back-calculation through the following sequential steps:

1. **Total Net Energy Demand Calculation:** The total biological Net Energy (NE) required by the animal stage is calculated to satisfy physiological demands (Maintenance, Activity, Pregnancy, Growth, and Lactation).
2. **Dietary Energy Supply Assessment:** The energy provided by all known dietary components (the defined quantities of compound feeds, silages, dry feeds, and the default milk volume) is calculated based on their specific Gross Energy (GE) contents and digestibility values.
3. **Remaining Energy Deficit:** The energy supplied by the known feed ingredients is subtracted from the animal's total energy demand to identify the remaining energy requirement.
4. **Fresh Grass Intake:** The required Dry Matter (DM) intake of fresh grass is estimated to bridge this remaining energy gap, accounting for the digestibility and energy availability of fresh pasture:

This approach ensures that the total feed intake meets the thermodynamic energy balance of the animal's biological cycle.

7.3.3.1 Nutritional Characteristics and Feed Formulations

Nutritional characteristics of the diet were defined according to ingredient-specific data sourced from externally available literature. In instances where specific nutritional data was unavailable, generic IPCC default values were applied.

Due to a lack of highly specific local origin data, the origin of compound feed ingredients was modeled at the European market average level.

Table 7-14: Total Feed Intake, Performance Metrics, and Primary Feed Shares per System and Animal Stage (ADG = Average Daily Gain, FCR = Feed Conversion Ratio)

System	Stage Name	Weight In (kg)	Weight Out (kg)	ADG (kg/d)	FCR	Total Feed (kg)	Compound Feed (%)	Fresh Grass (%)	Grass Silage (%)	Maize Silage (%)
BE_CC1	Beef cow, suckler extensive	750.0	750.0	-	-	277,633	0.0%	89.2 %	5.4%	0.0%
BE_CC1	Beef heifer, suckler ext.,	400.0	750.0	0.60	13.78	163,971	0.0%	39.4 %	60.6 %	0.0%

	replacement									
BE_CC1	Beef heifer, suckler ext., store	243.7	400.0	0.54	9.77	55,005	0.0%	14.2%	85.8%	0.0%
BE_CC1	Calves (Breeding Stage)	46.0	243.7	0.90	4.80	69,434	15.0%	32.7%	31.8%	0.0%
BE_CC2	Beef cow, suckler intensive	750.0	750.0	-	-	572,622	0.0%	45.0%	20.3%	14.9%
BE_CC2	Beef heifer, suckler int., replacement	475.0	750.0	0.80	12.20	228,083	0.0%	49.5%	21.1%	12.6%
BE_CC2	Beef heifer, suckler int., store	300.0	475.0	0.49	12.36	157,875	0.0%	33.3%	25.0%	16.7%
BE_CC2	Calves (Breeding Stage)	46.0	300.0	1.06	3.44	130,986	22.7%	0.0%	55.0%	0.0%
BE_CCF	Beef bull finished, breeder - fattener	300.0	600.0	0.83	9.74	125,600	18.5%	46.5%	16.5%	18.5%
BE_CCF	Beef cow finished, breeder - fattener	740.0	740.0	-	-	447,000	4.8%	42.1%	21.7%	14.5%
BE_CCF	Beef heifer, breeder - fat., replacement	636.0	750.0	0.80	13.40	59,569	3.8%	54.1%	17.2%	11.5%
BE_CCF	Beef heifer, breeder - fat., store	300.0	600.0	0.62	16.76	196,110	4.8%	47.5%	19.1%	14.3%
BE_CCF	Calves (Breeding Stage)	46.0	300.0	1.06	2.83	83,067	0.0%	50.7%	19.1%	1.5%
DE_LS_F	Dairy calves 1-2 yr finished, intensive	80.0	685.0	1.01	7.97	554,700	10.7%	0.0%	45.1%	35.2%
FR_CC1	Beef cow finished, suckler ext. cross	650.0	650.0	-	-	266,531	0.4%	32.9%	63.7%	0.0%
FR_CC1	Beef heifer finished,	650.0	725.0	0.70	14.12	18,004	3.5%	64.5%	22.0%	0.0%

	suckler ext. cross									
FR_CC1	Beef heifer, suckler ext. cross, repl.	297.8	650.0	0.70	11.03	124,381	0.6%	42.9 %	52.1 %	0.0%
FR_CC1	Calves (Breeding Stage)	43.5	297.8	1.00	2.94	56,070	21.5%	52.4 %	0.0%	0.0%
FR_CC2	Beef cow finished, suckler extensive	660.0	660.0	-	-	275,082	5.5%	35.9 %	58.6 %	0.0%
FR_CC2	Beef heifer finished, suckler extensive	283.8	815.0	0.66	12.76	40,672	9.3%	41.4 %	49.3 %	0.0%
FR_CC2	Beef heifer, suckler extensive, repl.	283.8	660.0	0.70	22.14	83,309	1.7%	77.3 %	21.0 %	0.0%
FR_CC2	Calves (Breeding Stage)	35.0	283.8	0.89	3.11	57,211	26.2%	7.2%	41.4 %	0.0%
FR_CCF (1)	Beef bull finished, breeder - fattener	297.8	737.0	1.95	5.57	70,930	29.2%	0.0%	0.0%	46.0 %
FR_CCF (1)	Beef cow finished, breeder - fattener	650.0	650.0	-	-	228,016	0.2%	23.0 %	40.2 %	20.5 %
FR_CCF (1)	Beef heifer, breeder - fat., replacement	297.8	655.0	0.67	12.21	126,472	3.3%	49.0 %	15.2 %	18.1 %
FR_CCF (1)	Calves (Breeding Stage)	49.0	297.8	0.98	3.10	47,770	3.0%	64.4 %	7.3%	0.0%
IT_F226	Beef bulls 1-2 year finished, intensive	220.0	520.0	1.00	5.14	348,630	12.3%	0.0%	11.8 %	0.0%
IT_F900	Beef calves 1-2 yr finished, intensive	420.0	687.0	1.27	9.38	2,287,522	8.7%	0.0%	0.0%	35.6 %

7.3.4 Manure Management and Housing

To accurately calculate manure-related emissions, specific housing and grazing timelines were established. The duration animals spend outdoors dictates the allocation of manure emissions between pasture and housing systems. Because this exact duration was not explicitly stated in the primary case studies, it was assumed that animals in the cow-calf breeding systems spend 7 months outdoors, based on qualitative data from the main publication and supported with the default data from *Common husbandry systems and practices for keeping beef cattle* (Cozzi at al. 2025)

The selected indoor manure management systems were directly modeled based on the qualitative descriptions provided in the primary case studies. For systems utilizing deep bedding, the timeline for manure removal (whether stored for over or under 1 month) was similarly selected in accordance with *Common husbandry systems and practices for keeping beef cattle* (Cozzi at al. 2025).

7.3.5 Allocation Parameters

Beef production systems are multi-output systems, resulting in various co-products leaving the farm gate (e.g., store calves, finished animals, culled breeding cows). Consequently, the environmental burdens of the system must be allocated among these outputs.

Allocation is calculated at the energy, mass and economic level utilizing established dry matter, energy content, and market price metrics. Market prices were sourced from EU Beef price statistics, and the biophysical energy content (MJ/kg) was derived using the energy balance models used to estimate feed requirements per IPCC guidelines.

Table 7-15: Allocation Parameters for Beef System Outputs

Output Product	Animal System	Stage	Allocation Needed	Mass Alloc. (Dry Matter)	Price (€/ton)	Biophysical (MJ/kg)
Cow	Beef	Breeding	Yes	43%	€4,871	36
Calf	Beef	Breeding	Yes	43%	€5,471	48

7.3.6 Farm Utilities, Water, and Bedding

Water Consumption Estimation

Water consumption across all animal stages is modeled dynamically using the established empirical equations from the National Academies of Sciences, Engineering, and Medicine (Ogino et al., 2016) for beef cattle. Rather than relying on static default values, the engine calculates the daily baseline water intake (liters/head/day) as a function of the animal's biological profile (Shrunk Body Weight) and the meteorological conditions of the farm's specific location (mapped via IPCC Climate Zones to FAO baselines). The model adapts the water estimation to specific physiological states—for instance, baseline intake for lactating cows is increased by a coefficient of 24% to account for milk synthesis. These estimations are then aggregated across the true herd size and stage duration.

Energy and Bedding Inputs

Energy consumption (diesel and electricity) and bedding material inputs at the farm level were derived from a supplementary LCA study (Ogino et al., 2016). Because animal sizes vary significantly across different beef production stages, these inputs were converted and standardized to represent quantities per Livestock Unit (LU) per year, allowing for dynamic scaling across the different herd profiles within systems.

Table 7-16: Energy and Bedding Consumption per Livestock Unit (LU)

Parameter	Finishing System	Cow-Calf System	Unit
Diesel	83.33	64.33	L/LU/year
Electricity	43.33	102.00	kWh/LU/year
Bedding - Straw	93.33	200.67	kg/LU/year
Bedding - Sawdust	8.33	-	kg/LU/year
Bedding – Cornstover	30.00	-	kg/LU/year

7.3.7 Emissions

Calculated emissions include CH_4 from enteric fermentation, as well as various manure management-related emissions: CH_4, direct and indirect N_2O, NH_3, NO_x, NMVOC, and PM2.5. All these emissions have been calculated using the Blonk Animal Life Cycle Engines (Blonk Consultants, 2020a, 2020b).

7.3.8 Limitations Beef System

While the datasets are modeled using high-resolution case studies to accurately reflect the heterogeneity of European beef production, several necessary assumptions and methodological choices introduce minor limitations to the model:

- **Fresh Grass Intake Estimation:** Because exact empirical data for grazed fresh grass is rarely available from farm-level statistics, grass intake is back-calculated using a theoretical energy balance model (based on IPCC 2019b equations). While this guarantees thermodynamic consistency between animal growth and total energy intake, the calculation relies on standard IPCC coefficients for activity, maintenance, and pasture digestibility, which may introduce minor theoretical approximations compared to directly measured pasture consumption.
- **Feed Origins:** Due to a lack of highly specific local origin data in the primary case studies, the origins of compound feed ingredients were modeled at the European market average level rather than being tailored to the exact country of the farm's production.
- **Housing and Pasture Timelines:** The precise duration animals spend on pasture dictates the allocation of manure emissions between the field and the stable. As these timelines were not strictly defined in the primary data, a standard assumption of 7 months outdoors was applied for cow-calf breeding systems, based on general European beef husbandry guidelines.
- **Manure Management Timelines:** For systems utilizing deep bedding, the timeline for manure removal (e.g., storage for over or under 1 month) was inferred based on common husbandry practices rather than explicit farm-level operational data.

- **Utility Inputs:** Farm-level electricity, diesel, and bedding inputs rely on a supplementary LCA study rather than primary data from the SustainBeef case studies. While standardized per Livestock Unit (LU), this introduces a minor discrepancy between the geographical specificity of the herd dynamics and the utility inputs.

7.4 Pig system

Pig fattening and pig breeding productions here described are single enterprise, 'conventional' animal production systems. High welfare and organic systems are not included. Countries/regions in scope are Belgium, Brazil, Denmark, France, Germany, Great Britain, the Netherlands, Spain, Europe and North America (Table 7-17).

Brazil data points are weighted averages of Mato Grosso and Santa Carolina regions (15% and 85% production share, respectively (IBGE, 2021). North America data points are weighted averages of United States of America and Canada (84% and 16% production share, respectively, based on (FAO, 2021b)). Europe data points are weight averages of various European countries, based on (Eurostat, 2021b) production shares on piglets (25% Spain, 24% Germany, 16% Netherlands, 13% Denmark, 11% France, 5% Belgium, 4% Great Britain, 2% Hungary and 1% Czechia) and pig (27% Spain, 25% Germany, 11% Netherlands, 11% Denmark, 12% France, 6% Belgium, 4% Great Britain, 3% Hungary and 1% Czechia).

Table 7-17: Data source used for the pig breeding and fattening LCIs.

Source	Parameter
(Hoste, 2020), country specific information	Pig reared per sow (every year), sow replacement rate, piglet weight at transfer, fattener target liveweight, fattener FCR, length of fattener production period, sow feed intake per year, gilt and pig mortality, feed consumption rearing phase.
(Hoste, 2023)	Weight gilts
(Topigs Norsvin, 2024)	Age gilts and feed consumption gilts
(Wageningen UR, 2021b), NL specific data	Sow and piglet mortality, gilt removals to slaughtering, price of sold animals, slaughtering weight of spent sow.
(UNFCCC, 2023), country specific & (IPCC, 2019a)	Manure management systems
(Wageningen UR, 2021a), NL specific data	Energy and water use.
(Kebreab et al., 2016)	Compound feed formulations
Personal communication (2010)	Compound feed formulations for NL
(Feedipedia, 2021)	Nutritional characteristics of compound feeds ingredients
(Centraal Veevoeder Bureau, 2016)	Nutritional characteristics of compound feeds ingredients for the systems "Pig fattening, dutch feed formulation, at farm/NL Economic", "Piglet, dutch feed formulation, at farm/NL Economic", and "Sow pig, dutch feed formulation, at farm/NL Economic"
(European Commission, 2024)	Climate types – for RER warm temperate moist was chosen.
Assumed	Weight at weaning, piglet production period, age at rearing and mortality at rearing

The production of pigs for slaughter is organized in two production stages.

In the first stage, sows are reared, inseminated and then go through a gestation period that concludes with the farrowing. New-born piglets are weaned with the mother sow, and then (after separation) reared up to a target weight for transfer. The second stage of the production system, the pig fattening stage, pigs are fattened to a target live weight. When the pigs have achieved the target weight, they are sent to slaughter. Only fatteners are considered in the slaughterhouse. This means that sows which are finished with breeding (and thus ready for slaughter) are not considered as input for the slaughterhouse. In Table 7-18 various population dynamic metrics for the breeding and fattening can be found.

Table 7-18: Piglet breeding and pig fattening animal average population and various population dynamic metrics.

Animal population and dynamics	BE	BR	DK	FR	DE	GB	NL	ES	RER	RNA
Gilt average population (#/sow)	0.16	0.15	0.13	0.14	0.12	0.13	0.13	0.17	0.14	0.15
Gilt removals to slaughtering (%)	3.2	2.3	3.4	3.8	2.7	3.2	2.4	4.1	3.2	4.5
Sow feed intake (kg/year)	1251	1093	1443	1338	1318	1370	1327	1148	1297	1226
Sow mortality (%)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Sow replacement rate (%)	42.2	45.0	53.3	45.1	39.4	55.0	41.0	45.4	44.6	44.3
Sow slaughtering weight (kg)	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0
Weaning piglet mortality (%)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Weaned piglet weight (kg)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Rearing piglet average population (#/sow)	3.9	3.8	6.0	5.3	5.3	5.9	4.5	3.0	4.6	4.0
Piglet rearing mortality (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Piglet rearing feed intake (kg/animal per round)	26.7	23.8	39.6	39.3	39.1	53.3	28.3	20.8	32.7	29.2
Piglet rearing production length (days)	51.7	50.1	67.6	67.4	67.2	81.8	56.0	41.9	58.7	55.1
Piglet weight at transfer (kg)	23.1	22.4	30.2	30.1	30.0	36.5	25.0	18.7	26.2	24.6
Pig reared per sow (#/year)	27.7	27.5	32.4	28.6	29.0	26.4	29.4	26.1	28.6	26.5
Fattener FCR (kg/kg)	2.7	2.4	2.6	2.8	2.8	2.7	2.6	2.5	2.7	2.7
Fattener production length (days)	132.7	115.2	85.3	111.6	108.7	86.1	114.9	129.9	113.7	120.9
Gilt production length (days)	174.2	172.6	183.1	182.9	182.7	193.8	175.0	167.9	177.7	175.4
Fattener and gilt mortality (%)	3.2	2.3	3.4	3.8	2.7	3.2	2.4	4.1	3.2	4.5
Fattener target weight (kg)	116.1	118.5	114.8	120.8	122.3	110.5	122.3	115.0	118.4	128.3
Gilt target weight (kg)	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0

For allocation between spent sows and piglets, the dry matter, energy content and prices of the various co-products need to be defined. These values have been based on Dutch values and are not country specific. The prices are based on (Wageningen UR, 2021b). The considered dry matter and gross energy content for spent sows is 47% and 11.44 MJ/kg, and 32% and 11.44 MJ/kg for piglets. Prices considered for spent sow and piglets are as defined in the animal life cycle engine documentation Blonk animal Life Cycle Engines (Blonk Consultants, 2020c).

Energy and water use was based on NL yearly data KWIN: 1828 MJ electricity/sow, 137 MJ electricity MJ/ fattener, 1293 MJ natural gas/sow, 41 MJ natural gas/fattener, 459 MJ diesel/sow, 34 MJ diesel/fattener, 7880 kg water/sow and 650 kg water/fattener. Only in the case of Brazilian production, no natural gas use was assumed.

For each country, a manure management mix has been considered (Table and

Table 7-20). Calculated emissions are CH_4 from enteric fermentation and various manure management related emissions: CH_4, N_2O direct and indirect, NH_3, NO_X, NMVOC, PM_{10}, $PM_{2.5}$ and TSP (Total Suspended Particle). All these emissions have been calculated with the Blonk animal Life Cycle Engines (Blonk Consultants, 2020c).

Table 7-19: Manure management system mix for various countries pig farms (UNFCCC, 2023) (IPCC, 2019a).

Manure management systems	BE (%)	BR (%)	DK (%)	FR (%)	DE (%)	GB (%)	NL (%)	ES (%)	RER (%)
Pit storage (1 month)	-	76.35	-	-	-		-	93.71	-
Pit storage (3 months)	-	-	-	-	-		-	-	-
Pit storage (4 months)	96.85	-	90.11	-	-		-	-	-
Pit storage (6 months)	-	-	-	86.68	80.43		42.25	-	80.48
Pit storage (12 months)	-		-	-	-	36.17	-	-	-
Daily spread	-	-	-	-	-	14.95	-	1.40	0.37
Solid storage and dry lot	3.15	-	0.10	5.76	2.99	34.04	40.55	3.92	9.48
Anaerobic digester, Low leakage, High quality industrial technology, open storage	-	-	-	7.00	16.58		-	-	9.55
Anaerobic digester; High leakage, low quality technology, high quality gastight storage technology	-	-	-	-	-		17.20	-	-
Anaerobic digester, High leakage, low quality technology, low quality gastight storage technology	-	11.11	9.40	-	-	4.45	-	-	-
Anaerobic digester, High leakage, low quality technology, open storage	-	-	-	-	-		-	0.97	-
Uncovered anaerobic lagoon	-	10.05	-	-	-		-	-	-
Composting	-	2.50	-	-	-		-	-	-
Pasture, range, and paddock	-	-	0.38	0.55	-	10.39	-	-	0.12

Table 7-20: Manure management system mix for pig farms in RNA ((UNFCCC, 2023)& (IPCC, 2019a)).

Manure management systems	Piglets (%)	Fattening pig (%)	Replacement Sow (%)	Sows (%)
Pit storage (12 months)	83.69	86.42	84.92	80.86
Uncovered anaerobic lagoon	14.47	11.78	13.22	16.97
Pasture, range, and paddock	1.30	1.26	1.32	1.63
Solid storage	0.54	0.54	0.54	0.54

Emission reduction at housing (either due to housing design or mitigation technology such as air washers) are not considered in these typical systems. This means that emissions (in particular ammonia and particulate matter emissions) might be overestimated compared to the average country's systems. This is especially relevant for countries where these systems are applied to a bigger extent such as the Netherlands.

Compound feed formulations, and their nutritional characteristics are described in Table 7-7-21. These are generic compound feed formulations, that are pre-defined weighted averages for different swine types (sow, piglet and growing pigs). This means that the feed ingredients and manure emissions are allocated to various animal stages in an approximate way. In

Table 7-22 Dutch specific compound feed formulations specific per animal type can be found; they were provided via personal communication with Agrifirm (2010).

The energy consumption for the manufacturing of the compound feed is based on the study that was performed for the Dutch Product Board Animal Feed (PDV) by Wageningen University and Blonk Consultants, in which life cycle inventories (LCIs) were developed for crop cultivations used in compound feeds. For one ton of compound feed, 315 MJ of electricity and 135 MJ of natural gas are required. The impact of transporting feed to the compound plant is included in the inputs (in form of "proxy market mix" or "market mix").

Table 7-7-21: Compound feed formulations, regions and animal type aggregated.

Feed Ingredient	Unit	BE/DE/DK/ES /FR/RER/GB	RNA	BR
Wheat grain, dried	%	37.9	-	-
Maize, dried	%	12.8	65.0	77.7
Barley grain, dried	%	31.1	-	-
Wheat bran, from wet milling	%	2.2	-	0.1
Rapeseed meal (solvent)	%	5.1	-	-
Soybean meal (solvent)	%	6.8	9.3	16.9
Crude rapeseed oil (solvent)	%	0.3	-	-
Soybeans, dried	%	0.01	-	-
Total minerals, additives, vitamins	%	1.1	2.1	2.1
Single superphosphate, as 35% Ca(H2PO4)2 (NPK 0-21-0)	%	0.2	0.1	0.2
Sodium chloride	%	0.4	0.4	0.4
Calcium carbonate, precipitated	%	1.8	1.5	0.9
Whey powder dried	%	0.2	0.2	-
Wheat middlings & feed	%	-	6.8	-
Sugar beet pulp dried	%	-	-	0.3
Fat from animals	%	-	-	1.4

Maize distillers grains dried	%	-	14.6	-
Total	*%*	*100.00*	*100.00*	*100.00*
Dry matter	%	87.5	87.7	87.1
Nitrogen content	% as is	2.2	2.4	2.4
Digestibility	% of GE	70.8	75.9	77.3

Table 7-22: Compound feed formulations, Dutch and animal type specific. Other ingredients have been excluded from the LCI.

Feed Ingredient	Unit	Piglets	Sows	Pigs
Wheat grain	%	26.0	13.0	25.0
Barley grain	%	36.0	21.0	29.0
Rye grain	%	-	4.0	3.0
Maize	%	6.0	4.0	2.0
Triticale grain	%	-	0.5	2.0
Oat grain	%	1.0	-	
Wheat middlings & feed	%	2.0	17.0	6.0
Wheat gluten feed	%	1.0	4.0	1.0
Maize middlings	%	-	2.0	1.0
Molasses	%	1.0	1.0	1.0
Sugar beet pulp dried	%	1.0	5.0	1.0
Crude palm oil	%	1.0	1.0	1.5
Soybean	%	4.0	-	-
Soybean meal (solvent)	%	13.0	4.5	8.0
Soybean hulls	%	-	5.5	0.5
Rapeseed meal (solvent)	%	2.0	4.0	10.0
Sunflower seed meal (solvent)	%	2.0	3.0	4.0
Palm kernel expeller	%	-	8.0	2.5
Fat from animals	%	-	0.5	0.5
Maize distillers grains dried	%	-	-	-
Wheat bran	%	-	-	-
Other	%	4.0	2.0	2.0
Total	*%*	*100.0*	*100.0*	*100.0*
Dry matter	%	87.2	88.3	87.5
Nitrogen content	% as is	2.8	2.8	2.8
Digestibility	% of GE	85	75	85

Table 7-23: Compound Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' swine farms per compound feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet

Type of animal	Compound feeds intake	Overall diet dry matter content	Overall diet crude protein content
NL	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Replacement sow	803	87.5	17.5
Rearing	161	87.2	17.5
Fattening	703	87.5	17.5
Breeding sow	1172	88.3	17.5
BE/DE/DK/ES /FR/RER/GB	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Replacement sow	803	87.5	13.75

Rearing	161	87.5	13.75
Fattening	703	87.5	13.75
Breeding sow	1172	87.5	13.75
BR	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Replacement sow	774	87.1	15
Rearing	151	87.1	15
Fattening	647	87.1	15
Breeding sow	965	87.1	15
RNA	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Replacement sow	788	87.7	15
Rearing	169	87.7	15
Fattening	753	87.7	15
Breeding sow	1082	87.7	15

7.4.1 Limitations Pig System

As seen in the section above, several assumptions were made to complete the data input. These include:

- Weight at weaning;
- Piglet production period;
- Age at rearing;
- Mortality at rearing.

Even though the inputs were based on expert knowledge they remain assumptions. Publicly available data will make the data points more accurate. Nevertheless, the assumptions made are expected to have limited effect on the results. For the manure management system in Great Britain, it was assumed that the pigs were located on a solid floor instead of a slated floor. Even though this is not completely aligned with the reality, this choice made the modelling, and thus the results, more reliable as the amount of liquid and solid manure was more accurately split. For the conversion factor for dietary gross energy per kilogram of dry matter the default value 18.45 of IPCC (2019) was used. It would be more accurate to determine the value on a single ingredient level. However, it is not expected that the average diet composition deviates largely from the IPCC suggested value; and thus, it will not have a significant effect on the results. Furthermore, currently the finished sows (sows that are done breeding) are not considered as input for the slaughterhouse process. This will have a limited effect on the results.

7.5 Poultry system

7.5.1 Laying hens system

The egg production systems described here are conventional, single-enterprise animal production systems. High-welfare and organic systems are not included. Countries/regions in scope are the Netherlands, Region Europe (RER) and North America (RNA) (

Table 7-24). All datapoints used for the North American systems were provided, through personal communication, by (Guyonnet, 2020).

The European dataset represents production in enriched cage systems and is a weighted average based on the share of eggs produced in various European countries: Spain (26%), Poland (19%), France (19%), Great Britain (15%), Italy (15%), the Netherlands (4%), Germany (2%), and Denmark (0.4%). These weights were calculated using data from FAO (2021d) and the European Commission (2018b).

The Dutch egg LCI is based on production data representative of an aviary housing system (a non-cage setup where laying hens are kept indoors in multi-tiered environments).

Data for the North American systems (cage-based) were obtained via personal communication with Guyonnet (2020). Furthermore, two types of North American farms have been distinguished based on their manure management systems: dry and wet.

Table 7-24: Data source used for egg production LCI.

Source	Country	Parameter
(Van Horne, 2018), country specific	RER	Laying period length, number of eggs per hen, egg average weight, and laying hen feed conversion ratio.
(Wageningen UR, 2021b), NL specific	NL	Laying period length, number of eggs per hen, egg average weight, and laying hen feed conversion ratio.
	NL, RER	Reared pullet average liveweight, pullet mortality, spent hen average weight, and laying hen mortality.
(Wageningen UR, 2021a), NL specific	NL, RER	Diesel use and natural gas use.
IPCC, 2006b, (UNFCCC 2023), default	NL, RER	Feed metabolizable energy, ash content, and manure management systems.
(Centraal Veevoeder Bureau, 2016), default	RER	Compound feed nutritional N content and dry matter content.
(Raamsdonk et al., 2007), NL specific	NL, RER	Pullet and laying hen feed formulation.
(Wageningen UR, 2021b), NL specific	NL, RER	Pullet rearing production length, pullet feed intake, bedding material use, electricity use, and water use.
(Wageningen UR, 2021b), NL specific	RNA	Bedding material use, and electricity use.
(European Commission, 2024)	NL, RER, RNA	Climate systems - for RER warm temperate moist was chosen.
(Guyonnet, 2020)	RNA	Laying period length, number of eggs per hen, egg average weight, laying hen feed conversion

		ratio, reared pullet average liveweight, pullet mortality, spent hen average weight, laying hen mortality, diesel use, natural gas use, feed metabolizable energy, ash content, compound feed nutritional N content, dry matter content, pullet and laying hen feed formulation, pullet rearing production length, pullet feed intake, and water use.
(EPA, 2023)	RNA	Manure management systems.

The production of consumption eggs consists of two animal production stages. In the first stage, the laying hens are reared up to approximately 17 weeks (pullet). In the second stage, the laying hens (> 17 weeks) start to produce eggs. After a single production period the laying hens are slaughtered. The breeding and hatching stage are considered the same for laying hens and broilers. The breeding and hatching stage are explained in Chapter 7.5.2.

All animal stages are modelled as per 100 animals entering the stage, except for the hatching stage which starts with 1000 eggs. In

Table 7-25, the population dynamics for the pullet rearing (<17 weeks) can be found, and in Table 7-26:, the population dynamics for the laying hens (> 17 weeks) are illustrated. For pullet rearing, downtime for cleaning has been included in the model. In contrast, for the laying production, empty days have not been considered.

Table 7-25: Pullet rearing (<17 weeks) population dynamic metrics (per round).

Animal population dynamics	Unit	NL	RER	RNA
Start weight one-day chicken	g/animal	42.0	42.0	42.0
End weight reared pullet	kg/animal	1.29	1.29	1.29
Pullets reared	#	96.0	96.0	97.1
Pullet mortality	%	4.0%	4.0%	2.9%
Pullet feed intake	kg/animal	5.25	5.25	5.94
Pullet rearing period length	days	140.0	140.0	126.0
Empty days between rounds	days	54.8	54.8	60.8

Table 7-26: Laying hens (>17 weeks) population dynamic metrics (per round).

Animal population dynamics	Unit	NL	RER	RNA
Average weight (input pullet)	kg/animal	1.3	1.3	1.3
Spent hen average weight	kg/animal	1.6	1.6	1.71
Number of eggs per hen	#/hen	433.6	362.8	421.5
Egg average weight	g/egg	61.1	62.9	61.5
Hen mortality	%	9.0	9.0	9.0
Layer feed intake	kg/animal	55.9	46.5	51.1
Laying hen feed conversion ratio	kg/kg egg	2.1	2.0	2.0
Laying period length	days	490.0	408.1	525.0
Empty period between rounds	days	0.0	0.0	0.0

Utility use is accounted for at farm level. For Dutch and European LCIs, utility use is 2.3 MJ electricity/pullet, with no diesel or natural gas attributed to pullets. Furthermore, the pullets use 0.2 kg sawdust/pullet, and 10 liter water/pullet. At the laying hen scale, values are 1.1 MJ

diesel/laying hen, 1.5 MJ natural gas/laying hen, 0.1 kg sawdust/laying hen, and 59.6 liter water/laying hen. Electricity consumption for hens differs between regions: 7.0 MJ electricity/laying hen in the Netherlands and 2.6 MJ electricity/laying hen in Europe. All utility data in the Netherlands and region Europea is based on (Wageningen UR, 2021b) and KWIN 2022-2023. For North American LCIs, utility use is 8.5 MJ electricity/pullet, 0.1 MJ diesel/pullet, 0.1 MJ gasoline/pullet, 1.3 MJ (propane and/or LPG)/pullet, 3.8 MJ natural gas/pullet, 11 L water/pullet, and 0.2 kg sawdust/pullet. For the North American laying hens, the values are 14.4 MJ electricity/pullet, 1.8 MJ diesel/pullet, 0.2 MJ gasoline/pullet, 2.1 MJ (propane and/or LPG)/pullet, 0.1 MJ natural gas/pullet, 110 L water/pullet, and no bedding.

Poultry manure was considered the same in all three regions. In accordance with the IPCC (2019a) and the U.S. Environmental Protection Agency (2023), the manure management system for laying hens < 17 was *poultry manure with or without litter* and the poultry manure for laying hens > 17 was *solid*. For North America, an additional scenario was considered where anaerobic lagoon management is applied – a common practice in that region but rarely used in Europe.

The emissions only linked to manure management include: CH_4, direct and indirect N_2O, NH_3, NO_x, NMVOC, PM_{10}, $PM_{2.5}$, and total suspended particulates (TSP). All these emissions have been calculated with the Blonk animal Life Cycle Engines (Blonk Consultants, 2020a, 2020c). Emission reductions due to housing design or mitigation technologies (e.g., air washers) are not considered. This means that the emissions, in particular ammonia and particulate matter emissions, may be overestimated compared to the average national system.

Feed composition for laying hens <17 weeks and >17 weeks in Dutch and European LCIs is based on Raamsdonk et al. (2007, RIKILT) (Table 7-27**Error! Reference source not found.**). For North America, formulations are based on Guyonnet (2020). Energy requirements for all compound feed production are based on a study conducted by Wageningen University and Blonk Consultants for the Dutch Product Board Animal Feed (PDV), which developed LCIs for crop cultivation used in feed production. Per ton of compound feed, 315 MJ electricity and 135 MJ natural gas are required. Feed transport is not included in these LCIs.

Table 7-27: Pullet (<17 weeks) and laying hen (>17 weeks) compound feed formulations.

Feed Ingredient	Unit	Pullet (<17 weeks)		Laying hen (>17 weeks)	
		NL/RER	RNA	NL/RER	RNA
Barley grain	%	1.5	7.0	1.1	-
Maize	%	38.6	36.1	32.8	60.1
Wheat grain	%	13.3	29.0	20.9	-
Wheat bran	%	3.7	-	4.1	-
Wheat gluten feed	%	-	-	0.7	-
Wheat middlings & feed	%	-	2.4	-	-
Rapeseed meal (solvent)	%	-	1.0	-	-
Maize gluten feed, dried	%	1.6	-	1.5	-
Soybean meal (solvent)	%	15.5	16.4	13.5	26.7
Sunflower seed meal (solvent)	%	2.6	-	3.2	-
Cassava root, dried	%	0.9	-	1.5	-
Molasses	%	0.1	-	0.1	-
Animal meal	%	-	2.7	-	-
Maize distillers grains dried	%	-	2.5	-	-
Crude palm oil	%	-	-	0.004	-
Crude soybean oil (solvent)	%	-	-	-	1.8
Crude rapeseed oil (solvent)	%	-	0.5	-	-
Sodium chloride, powder	%	-	0.4	-	0.3
Fat from animals	%	3.4	0.1	3.4	-

Peas, dry	%	1.2	0.6	2.2	-
Soybean, heat treated	%	5.6	-	2.7	-
Soybeans	%	-	-	0.3	-
Limestone, unprocessed	%	8.8	1.1	9.1	9.6
Total minerals, additives, vitamins	%	-	0.5	-	1.5
Other	%	3.2	-	3.1	-
Total	*%*	*100.0*	*100.0*	*100.0*	*100.0*
Dry matter	%	88.0	87.56	87.0	87.7
Nitrogen content	% as is	4.2	2.7	2.7	2.8
Metabolizable energy	% of DM	75.0	73.5	75.0	73.5

Table 7-28: Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' poultry farms per various feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet.

Type of animal	Compound feeds intake	Overall diet dry matter content	Overall diet crude protein content
NL	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Pullet (<17 weeks)	4.44	88.00	26.14
Laying hen (>17 weeks)	46.41	87.00	17.17
RER	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Pullet (<17 weeks)	4.44	88.00	26.14
Laying hen (>17 weeks)	38.62	87.00	17.17
USA	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Pullet (<17 weeks)	5.05	87.56	17.00
Laying hen (>17 weeks)	44.78	87.70	17.50

7.5.2 Broilers system

Broiler production here described are single enterprise, conventional animal production systems. High welfare and organic systems are not included. Countries/regions in scope are the Brazil, China, France, Japan, the Netherlands, Thailand, United States and Region Europe.

The production of broilers for chicken meat consists of three animal production stages and a hatchery. In the first stage, one-day chicks are bred up to 20 weeks (parent rearing). In the second stage, the pullets (>20 weeks), also known as bird parents, start to produce eggs for hatching (broiler breeding). After a production period, the bird parents are slaughtered. The eggs produced by the bird parents are hatched in a hatchery (egg hatching) and consequently result in one-day-chicks. These one-day-chicks can become laying hens (Chapter 7.5.2), breeding parents or broilers. The growing to broilers is the third stage (broiler fattening), in which the one-day-chicks are reared in a couple of weeks and slaughtered to produce chicken meat.

All animal stages are modelled as per 100 animals entering the stage, except for the hatching stage which starts with 1000 eggs.

The modelling of egg hatching, parent rearing and broiler breeding has been fully based on (Wageningen UR, 2021b) for all countries in scope. The sources for the broiler fattening are listed in Table 7-29Table 7-29**Error! Reference source not found.**.

Table 7-29: Data sources used for the broiler fattening LCI.

Source	Country	Parameter

Broiler Production System Life Cycle Assessment: 2020 Update	US	Broiler average target weight, broiler energy use, broiler water use, broiler bedding material use, broiler production length, broiler mortality rate, broiler FCR, rooster input, broiler compound feed formulation.
(Prudêncio da Silva et al., 2014)	BR, FR	Broiler production length, broiler mortality rate
	BR	Broiler FCR, broiler average target weight
(van Horne, 2019)	FR, RER	Broiler FCR, broiler average target weight
(Wageningen UR, 2021b), NL specific (KWIN 2023-2024)	All, except US	Broiler bedding material use, broiler energy use, broiler water use, rooster input.
Personal communication with regional industry experts (2020)	NL, JP, CN, TH, RER	Broiler production length
	NL, JP, CN, TH, RER, US	Broiler: Empty period for cleaning
	NL, JP, CN, TH	Broiler FCR, broiler average target weight.
(CBS (Centraal Bureau voor de Statistiek), 2019)	All	One day-chicken weight.
(Personal Communication, 2013)	All	Broiler parents (rearing and one-day chicken breeding) compound feed formulations.
(FAO, 2018c)	All, except US	Broiler compound feed formulation.
Assumed	All	Broiler cleaning period length
	All, except US	Broiler mortality rate.
(European Commission, 2024)	All	Climate systems - for RER & USA warm temperate moist was chosen.

The houses are not filled with animals throughout the whole year, but they remain empty for cleaning in between production rounds. In Table 7-30, the key parameters for the egg hatching, parent rearing and broiler breeding are described. In

Table 7-31, the key parameters for the broiler fattening are described.

Table 7-30. Key parameters for the hatchery, Parent rearing and breeding stage for all countries in scope (Per Round).

Stage	Parameter	Unit	Value
Egg hatching	Transport distance of hatching eggs	km	100.0
	Egg weight	g/egg	61.5
	One day chicken per hatched egg	#/#	0.8
	On-day chicken weight	g/animal	42.0
Parent rearing	Pullet compound feed intake	kg/reared pullet	4.4
	Pullet mortality rate	%	11.0
	Reared pullet liveweight (end-weight)	kg/animal	2.3
	Parent rearing period length	days	140.0
	Parent rearing empty period length	days	21.0
Broiler breeding	Incoming hens	#	96.0
	Incoming roosters	#	4.0
	Parent mortality during one-day chicken breeding	%	2.2
	Parent weight at the end of the cycle	kg/animal	3.9
	Parent FCR during one-day chicken breeding	kg/kg egg	4.2
	Hatching egg output	eggs/reared pullet	174.0
	Infertile egg output	eggs/reared pullet	10.0
	One-day chicken breeding period length	days	286.0
	One-day chicken breeding empty period length	days	40.0

Table 7-31. Key parameters for the broiler Fattening Production SYSTEM (Per round).

Parameter	Unit	FR	NL	BR	RER	US	JP	CN	TH
Broiler target weight	kg/ animal	1.90	2.83	2.44	2.28	2.89	3.00	1.55	2.15
Broiler mortality rate	%	4.10	3.20	4.30	3.20	7.15	3.20	3.20	3.20
Broiler FCR	kg/kg	1.67	1.55	1.88	1.63	1.79	1.55	1.67	1.44
Broiler period round length	days	48.00	50.00	50.00	50.00	55.00	54.00	37.00	46.50
Broiler empty period length	days	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00

The broiler breeding produces hatching eggs, infertile eggs as well as spent parents which are slaughtered for meat. This requires allocation of the environmental impact to the products. Considered dry matter contents are 21% and 35% for eggs and spent animals, respectively. Gross energy contents are set at 6.3 MJ/kg and 9.19 MJ/kg for eggs and spent animals, respectively. Considered prices are 3036 euro/kg, 81 euro/kg and 449 euro/kg for hatching eggs, infertile eggs and spent animals, respectively.

Each of the various stages requires input of bedding material, water and energy. The parent rearing to 20 weeks uses 1.0 kg straw/pullet reared, 20.0 kg water/pullet reared, 2.7 MJ electricity/pullet reared, and 15.83 MJ heat/pullet reared. The broiler breeding stage requires 1.00 kg straw/parent, 100 kg water/parent, 14.4 MJ electricity/parent and 8.9 MJ heat/hatching eggs. The egg hatchery is considered to be using 0.43 MJ heat/egg. For the broiler fattening stage, all countries in scope except for the USA were assumed to require 8.7 kg straw/broiler, 51.1 kg water/ broiler, 2.9 MJ electricity/ broiler and 19.8 MJ heat/broiler. The US broiler farm has an input of 0.2 kg straw/broiler, 68.9 kg water/broiler, 0.9 MJ electricity/broiler, 3.3 MJ heat/broiler, and 0.2 MJ diesel/broiler.

Poultry manure was considered the same in all regions. In accordance with the IPCC (2019a), the manure management system for parent rearing and broiler fattening is *poultry manure with or without litter* for all regions, and for broiler breeding is *solid*.

The emissions only linked to manure management include: CH_4, direct and indirect N_2O, NH_3, NO_x, NMVOC, PM_{10}, $PM_{2.5}$, and TSP. All these emissions have been calculated with the Blonk animal Life Cycle Engines (Blonk Consultants, 2020a, 2020c). Emission reductions due to housing design or mitigation technologies (e.g., air washers) are not considered. This means that the emissions, in particular ammonia and particulate matter emissions, may be overestimated compared to the average national system.

The feed composition for parent rearing, broiler breeding and broiler fattening (Table 7-32) is based on confidential information from major feed producer in the Netherlands (data from 2010) and data derived from GLEAM model (FAO, 2018c), respectively. The feed composition for the broiler fattening stage of the US is based on Thoma & Putman (2020).

Energy requirements for compound feed production are based on a study conducted by Wageningen University and Blonk Consultants for the Dutch Product Board Animal Feed (PDV), which developed LCIs for crop cultivation used in feed production. Per ton of compound feed, 315 MJ electricity and 135 MJ natural gas are required. Feed transport is not included in these LCIs.

Table 7-32. Feed rations for parent rearing (broiler parents < 20 weeks), broiler breeding (broiler parents > 20 weeks) and broiler fattening (broilers).

Feed Ingredient	Unit	Broiler parents		Broilers					
		<20 weeks	>20 weeks	RER	FR	NL	JP & CN	BR & TH	US
Barley grain	%	3.0	7.0	-	-	-	5.0	-	-
Maize	%	26.0	17.0	22.5	25.0	20.0	39.0	71.0	70.2
Sorghum grain	%	-	-	3.5	-	-	9.0	-	-
Wheat grain	%	28.5	34.0	41.9	41.0	48.0	18.0	-	-
Wheat bran	%	7.5	12.0	-	-	-		-	-
Wheat gluten meal	%	1.5	1.3	-	-	-		-	-
Maize gluten meal	%	1.5	0.5	-	-	-		-	-
Soybean meal (solvent)	%	6.5	3.0	25.2	24.0	25.0	23.0	27.0	26.7
Sunflower seed meal (solvent)	%	6.0	13.0	-	-	-	-	-	-
Rapeseed meal (solvent)	%	5.5	6.0	4.8	8.0	5.0	2.0	-	-
Oat grain	%	0.5	1.0	-	-	-		-	-
Crude palm oil	%	0.5	0.3	-	-	-		-	-
Fat from animals	%	2.5	1.0	-	-	-		-	-
Peas, dry	%	0.5	-	-	-	-		-	-
Maize distillers grains	%	-	-	-	-	-		-	2.7
Fish meal	%	-	-	-	-	-	2.0	-	-
Meat bone meal	%	-	-	-	-	-		-	-
Citrus pulp dried	%	6.5	-	-	-	-		-	-
Calcium carbonate, precipitated	%	-	-	1.0	1.0	1.0	1.0	1.0	-
Total minerals, additives, vitamins	%	-	-	1.0	1.0	1.0	1.0	1.0	0.5
Other	%	3.5	4.0	-	-	-	-	-	-
Total	*%*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
Dry matter	%	88.1	87.7	88.0	88.1	88.0	87.6	87.0	88.0
Nitrogen content	% as is	3.0	3.1	3.4	3.4	3.4	3.5	3.4	3.8
Metabolizable energy	% of DM	75.0	75.0	76.4	78.0	77.4	74.5	74.5	81.7

Table 7-33: Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' poultry farms per various feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet.

Type of animal	Compound feeds intake	Overall diet dry matter content	Overall diet crude protein content
NL	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	3.67	88.00	21.31
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
RER	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	3.11	88.00	0.00
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
BR	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	3.74	87.00	21.55

Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
CN	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	2.14	87.60	22.12
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
FR	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	2.62	88.10	21.28
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
JP	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	3.89	87.60	22.12
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
TH	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	2.55	87.00	21.55
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60
US	**DMI, kg/animal/year**	**DM, %**	**CP, % of DM**
Parent rearing (broiler parents < 20 weeks)	8.81	88.10	18.80
Broiler fattening (broilers)	3.66	88.00	23.44
Broiler breeding (broiler parents > 20 weeks)	41.75	87.70	19.60

7.5.3 Limitations Poultry System

While modelling the poultry system several assumptions were made that affected the outcome. For example, for the breeding and laying stage it was assumed that all the manure produced was solid. In the National Inventory Report (UNFCCC, 2023) a part of the manure was classified as “other”. Considering that the largest part was classified as “solid” it was assumed that “other” was also “solid”. This has a large influence on the results, because the methane conversion factor differs by manure management type. Meaning that a different manure management system with a very different methane conversion factor compared to solid will provide a different amount of manure emissions. Nevertheless, as solid manure is the common manure management system for poultry in Europe this assumption will likely give results in the right order of magnitude.

Furthermore, the poultry system for Region Europe was modelled with a large amount of data from the Netherlands. This means that it is not fully representative of the European situation as Europe also has other large poultry producing countries. However, for broiler fattening and laying hens, European average data was used. The outcome would be more representative if for all data points an average European value was chosen. Nevertheless, the results still represent a European average as also European values were used.

Another improvement point is the modelling of feed intake and sold eggs. For example, for the USA pullet rearing the amount of feed intake and sold eggs was modelled with the starting bird population, whereas for the Netherlands and Region Europe, the average population was used for modelling. The effect on the results will be minimal as the number of incoming animals is similar to the average population.

For the conversion factor for dietary gross energy per kilogram of dry matter the default value 18.45 of IPCC (2019) was used. It would be more accurate to determine the value on a single ingredient level. However, it is not expected the average diet composition will deviate largely from the IPCC suggested value; and thus, it will not have a significant effect on the results

7.6 Slaughterhouse

Animals are slaughtered for meat production in a slaughterhouse. The live weight of the animals is separated into fresh meat, food grade, feed grade and other products (non-food and non-feed) (Luske & Blonk, 2009), according to the mass balance shown in Table 7-34**Error! Reference source not found.**.

Table 7-34: Mass balances of the slaughterhouses for different animal types (Luske & Blonk, 2009).

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

The energy consumption and water consumption at slaughtering is based on Dutch data (www.routekaartvlees.nl, 2012). They are shown in Table 7-35 to Table 7-38.

The water use is not split up transparently in the 'ketenkaarten[8]' (www.routekaartvlees.nl, 2012), so the remainder of the total is assumed to be for general facilities, but some of this can probably be attributed to the slaughterhouse processes directly. Another limitation of the modelling is that a generic ecoinvent process is used to model wastewater, thus not a specific slaughterhouse wastewater processing process. The production of four products from the slaughterhouse (fresh meat, food grade, feed grade and other - non-food & non-feed) requires allocation. This is based on mass (as is), energy content as well as financial revenue. The results are highly dependent on the choice of allocation. The fresh meat and food grade will have the highest financial revenue, but the feed grade and other non-food and non-feed products represent a significant amount of the mass of all final products. See Table 7-38.

Table 7-35: Energy and water consumption for chicken meat in the slaughterhouse.

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

[8] Ketenkaarten is the name used for the maps from www.routekaartvlees.nl made to display the overview of the supply chain.

Table 7-36: Energy and water consumption for pig meat production in the slaughterhouse.

Production line	Action	Electricity (MJ/kg LW)	Natural gas (MJ/kg LW)	Water (l/kg LW)
Slaughter line	Slaughtering process	0.01	-	0.16
	Heating tray	-	0.03	-
	Oven	-	0.15	-
	Washing	-	-	-
Cooling line	Dry air cooling	0.14	-	-
	Spray cooling	0.11	-	0.16
	Cooling the workspace	0.09	-	-
	Cutting and deboning	0.001	-	-
General facilities		0.032	0.06	2.15
Total		0.383	0.24	2.47

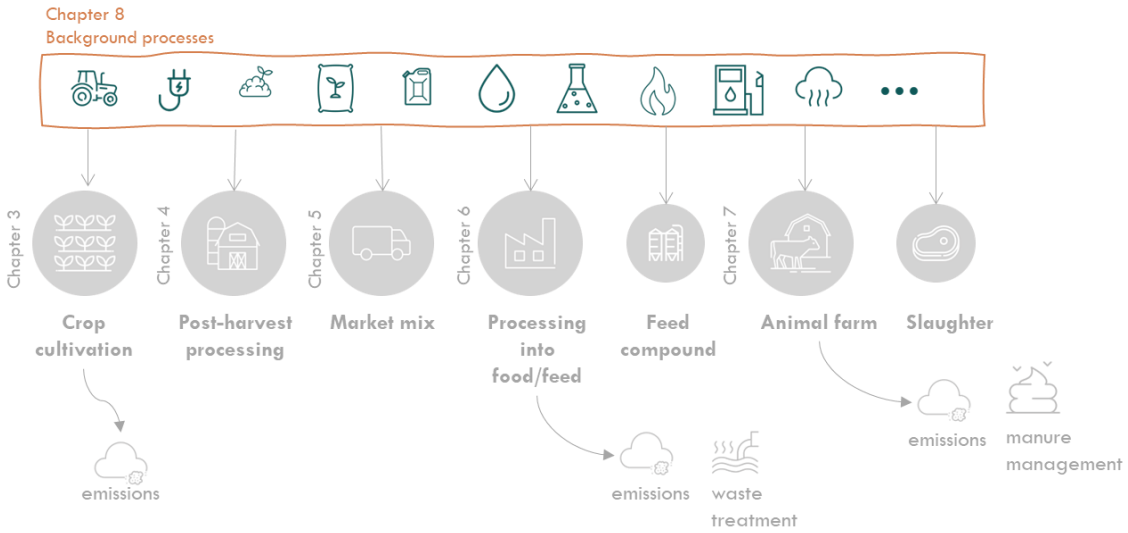
Table 7-37: Energy and water consumption for beef in the slaughterhouse.

Production line	Action	Electricity (MJ/kg LW)	Natural gas (MJ/kg LW)	Water (l/kg LW)
Slaughter line	Slaughtering process	0.01	-	0.29
	Heating of water	-	0.11	-
	Removing the skin	-	-	0.36
Cooling line	Dry air cooling	0.27	-	-
	Spray cooling	-	-	-
	Packing	0.001		-
	Cooling the workspace	0.06	-	0.01
	Cutting and deboning	0.002	-	0.08
Cleaning line	Removing the organs	-	-	0.07
General facilities		0.048	0.04	1.19
Total		0.391	0.15	2.0

Table 7-38: Key parameters required for economic allocation and allocation based on energy content (Blonk et al., 2007), (Kool et al., 2010).

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

8. Background processes



8.1 Adjustment in water processes

All ecoinvent background processes that are used in Agri-footprint are exact copies from the ecoinvent v3.12 database, except for the wastewater and tap water processes. In these copied processes from ecoinvent, all water flows have been deleted. The original wastewater and tap water processes in ecoinvent "produce" and "consume" water, which from a material balance point of view is correct. But this can result in negative water consumption for agricultural products in case the crop is cultivated without irrigation. To avoid negative water consumption of agricultural products and to comply with the ISO 14046 on water footprint (ISO 14046, 2014), it was chosen to remove all water flows from the wastewater background dataset. Hereby no water can be "produced" at wastewater processing due to the altered wastewater process in Agri-footprint, contrary to the original dataset from ecoinvent which has negative water consumption. All other impacts related to wastewater processing (electricity, chemical use, etc.) are still included and are identical between ecoinvent and the altered dataset in Agri-footprint. This results in these processes representing the impacts associated with wastewater processing and tap water production, except for the water flows themselves. For tap water specifically, regionalized water flows are added separately when the process is used. This means that tap water is always used in conjunction with regionalized water inputs to account for these differences.

8.2 Transport processes

8.2.1 Road

All truck transport datasets available in Agri-footprint are derived from (Klein et al., 2012a, 2012b). Currently, no cooled or frozen transport is included in Agri-footprint. Fuel consumption for road transport is based on primary activity data of multiple types of vehicles (Table 8-1). These data have been categorized into three types of road transport: small trucks (<10t) medium sized trucks (10-20t) and large trucks (>20t). Small trucks have an average load capacity of 3 ton; medium trucks have an average load capacity of 6.2 ton and large trucks have an average load capacity of 24 ton average.

Small, medium and large trucks have a fuel consumption that is the average within the category of the primary activity data (Table 8-2). Because fuel consumption has been measured for fully loaded as well as for empty vehicles, the fuel consumption can be adapted to the load factor (share of load capacity used) by assuming a linear relationship between load factor and marginal fuel use.

Table 8-1: Primary activity data for the fuel consumption of road transport (Klein et al., 2012b)

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

Table 8-2: Categorized primary activity data for vans, small trucks and large trucks.

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

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

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

Five types of emissions standards are defined: EURO1, EURO2, EURO3, EURO4 and EURO5. These emissions standards correspond with the European emission standards and define the acceptable limits for exhaust emissions of new vehicles sold in EU member states. The emission standards were defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards. Currently, emissions of nitrogen

oxides (NO_x), carbon monoxide (CO) and particulate matter (PM) are regulated for most vehicle types. The emissions decreased from EURO1 to EURO5. Agri-footprint 8 currently only uses EURO 4 and EURO 5 datasets to model the impact of logistics, but the user has the option to use lower emission standard datasets since EURO 1, 2 and 3 are also available in Agri-footprint but not used by default.

The naming of the processes is built up of several types of information. First of all, it is a 'Transport, truck,' process. The load capacity is given in ton (t), and the emission standard is also given (EURO1-EURO5). The load factor, which is the percentage of the load capacity, which is being occupied, is given in % (%LF). Finally, there are two options related to the return trip. A vehicle can make a complete empty return trip, indicated by 'empty return'. This means that the emissions include a return trip of the same distance but instead of the load factor, which was applied to the first trip, the load factor for the return trip is 0%. In many cases there is no information on the return trip. The vehicle can drive a couple of km to another location to pick up a new load or may have to drive a long distance before loading a new load. Usually, the vehicle will not directly be reloaded on the site of the first destination. As a 'default' the assumption has been made that an added 20% of the emissions of the first trip are dedicated to the return trip, based on indications that 21% of the kms truck transport are driven with empty load (European Commission, 2018c). Indirectly the assumption is made that a certain amount of the trip to the next location is dedicated to the first trip.

For all truck transports within Agri-footprint 8, the "default" truck mode is selected, except for transport to cultivation, meaning all inputs like manure, fertilizer, lime, pesticides and seeds used for transport to farm an "empty return" truck mode is selected. This is assumed since nothing else can be transported from the farm, resulting in an "empty return" of the transport.

8.2.2 Water

8.2.2.1 Barge

The fuel consumption of barge ships is based on a publication of CE Delft (Den Boer et al., 2008). There are barge ships which transport bulk (5 types) and barge ships which transport containers (4 types). The types of ships differ in the load capacity and in the fuel consumption (Table 8-3).

Table 8-3: Fuel consumption of 5 types of bulk barges and 4 types of container barges. Based on (Den Boer et al., 2008).

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

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

8.2.2.2 Sea ship

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

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

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

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

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

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

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

Step 2: Calculate empty weight (LDT)

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

Step 3: Calculate the maximum ballast weight (BWT)

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

Step 4: Calculate the cruising time

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

Step 5: Calculate the load

Load (ton) = DWT * load factor

Step 6: Calculate the total weight of the ship

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

Step 7: Calculate the maximum total weight of the ship

Maximum weight (ton) = DWT + LDT

Step 8: Calculate the actual engine power used per phase

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

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

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

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

Step 9: Calculate the fuel consumption per phase

Fuel consumption (GJ) per phase i =

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

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

Step 11: Calculate the fuel consumption per tkm

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

Because the trip distance has a large impact on the fuel consumption and the processes that are based on tkm, the trip distances have been categorized by: ‘short’, ‘middle’ and ‘long’. The short distance can be used for trips shorter than 5,000 km, and its fuel consumption has been calculated using a distance of 2,500 km. The middle distance can be used for trips which are 5,000 – 10,000 km and the fuel consumption has been calculated using a distance of 8,700 km. The long distance can be used for trips longer than 10,000 km, and the fuel consumption

based on a distance trip of 20,500 km. The fuel type for sea ships is heavy fuel oil. The fraction of fuel used for cruising, slow cruising, maneuvering, and hoteling is displayed in Table 8-4. (Klein et al., 2012b).

Table 8-4: Fraction of fuel used for traveling phases for short, middle and long distances for sea ships.

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

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

8.2.3 Rail

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

Two general assumptions have been made:

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

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

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

Where the abbreviations are explained as follows:

- NW: Number of wagons
- LF: Load factor

- LCW: Load capacity wagon
- WW: Weight of wagon
- TCW: Twenty-foot Equivalent Unit (TEU) capacity per wagon
- UC: Utilization TEU capacity
- CL: Maximum load per TEU

Table 8-5 displays the values of the wagon specifications which have been used to calculate the fuel consumption of freight trains transporting bulk or containers.

Table 8-5 Wagon specifications required to calculate the gross weight of freight trains.

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

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

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

For all train transports within Agri-footprint the "default" train mode is selected, except for bulk transport to fertilizer plants.

8.2.4 Air

The fuel consumption of airplanes is based on a publication of the European Environment Agency (European Environment Agency, 2006). Three types of airplanes have been selected: Boeing 747-200F, Boeing 747-400F and Fokker 100. The specifications of these airplanes are given in Table 8-6.

Table 8-6: Specification of the airplanes Boeing 747-200F, Boeing 747-400F and Fokker 100.

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

Two assumptions have been made:

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

The fuel consumption of the airplanes is shown in

Table 8-7, Table 8-8 and

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

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

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

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

Table 8-7 shoes the payload for the long distance. Processes are named based on a couple of types of information. First of all, it is a 'Transport' process, and secondly it is an airplane. Three types of airplanes can be selected: Boeing 747-200F, Boeing 747-400F and Fokker 100. Finally, the trip length can be selected: 'short', 'middle' or 'long'.

Table 8-7: Fuel consumption of a Boeing 747-200F

Distance (km)	232	463	926	1389	1852	2778	3704	4630	5556	6482	7408	8334	9260	10168
Flight total fuel (kg)	6,565	9,420	14,308	19,196	24,084	34,170	44,419	55,255	66,562	77,909	90,362	103,265	116,703	130,411
LTO	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414	3,414
Taxi-out	702	702	702	702	702	702	702	702	702	702	702	702	702	702
Take-off	387	387	387	387	387	387	387	387	387	387	387	387	387	387

Climb-out	996	996	996	996	996	996	996	996	996	996	996	996	996	996
Climb/cruise/descent	3,151	6,006	10,894	15,782	20,671	30,757	41,005	51,841	63,148	74,495	86,948	99,852	113,289	126,997
Approach landing	626	626	626	626	626	626	626	626	626	626	626	626	626	626
Taxi-in	702	702	702	702	702	702	702	702	702	702	702	702	702	702

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

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

Table 8-9: Fuel consumption of a Fokker 100

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

8.3 Fertilizers production

The update regards the implementation of regionalized energy input/production for Ammonia and N_2O emissions for nitric acid. All the other fertilizers production was modelled based on (Kongshaug, 1998) and (Davis & Haglund, 1999). Davis & Haglund (1999) describes the production processes of these fertilizers in detail. The energy use and block approach have been taken from Kongshaug (1998), while additional data on emissions were sourced from Davis and Haglund, the electric energy consumption is normally very small, thus the energy losses from the production of electric energy is not included (Kongshaug, 1998). Based on these sources, heat, water and electricity inputs are included. This results in some fertilizers lacking one or more of these inputs. Background processes (such as heat and electricity) implemented in Agri-footprint 8 are copied from the ecoinvent v3.12 database. Figure 20 shows the product flow diagram for fertilizer production. As can be seen in Figure 20, some fertilizers are produced using a combination of intermediate products and/or other fertilizer products. The updated inventories for fertilizer production are listed in

Table 8-10 to Table 8-24. Only the inventories for European fertilizer products are shown here. The important intermediate product phosphoric acid is described in

Table 8-10.

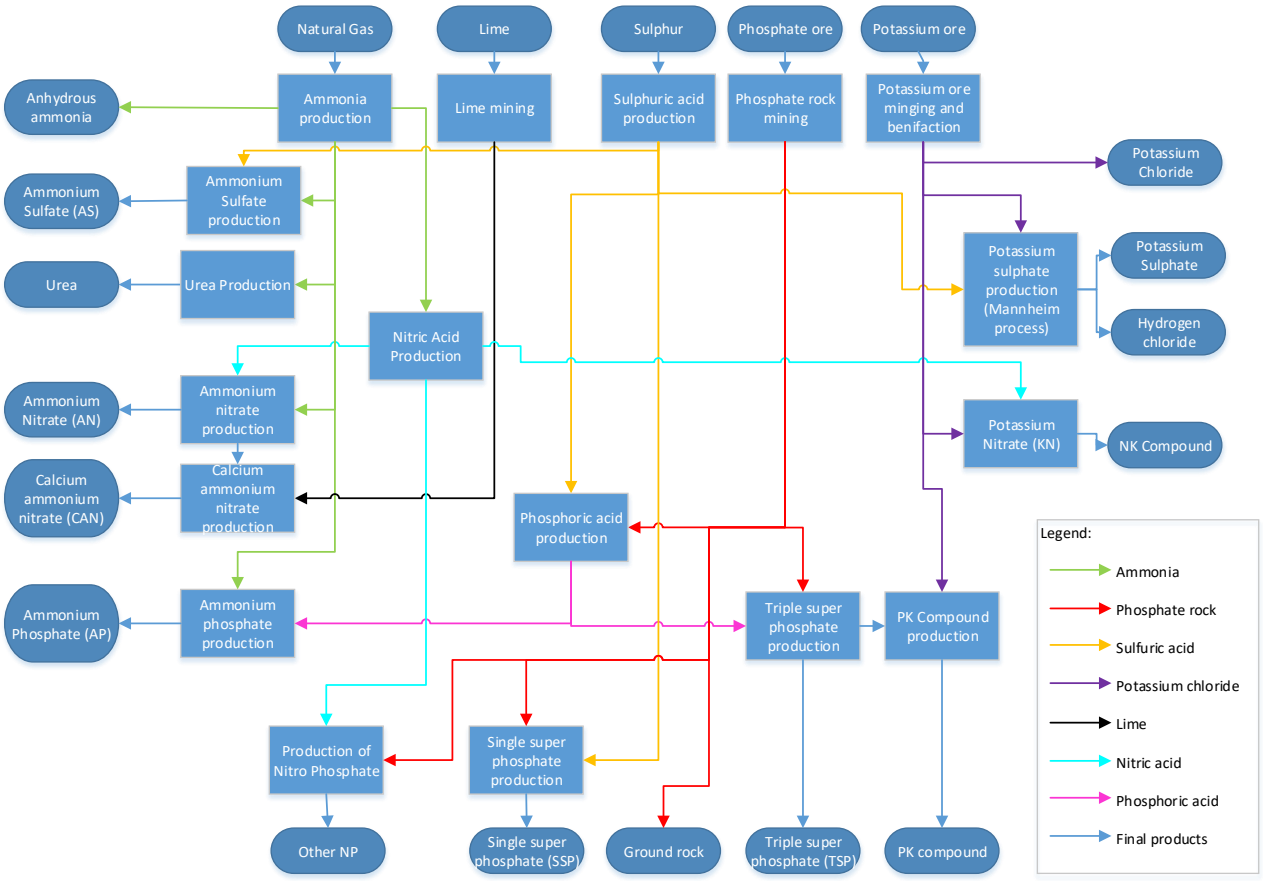


Figure 20: Product flow diagram for fertilizer production. The colored lines indicate specific intermediate flows (see legend). Raw materials are listed on the top of the figure, N fertilizers are listed on the left, P fertilizers on the bottom, K fertilizers on the right. Figure based on description in Kongshaug (1998).

Table 8-10 Inventory for phosphoric acid.

	Unit	Quantity	Comment
Products			
Phosphoric acid, merchant grade (75% H_3PO_4) (NPK 0-54-0), at plant /RER	kg	1000	
Materials/fuels			
Phosphate rock (32% P_2O_5, 50% CaO) (NPK 0-32-0) /RER	kg	1687	based on P balance
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	1490	-
De-ionised water	kg	420	-
Transport, sea ship, 60000 DWT, 100%LF, short, default/GLO	tkm	506	transport of phosphate rock from western Sahara to port in Europe
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	110	transport of phosphate rock from port to phosphoric acid production plant
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	3860	transport of sulfuric acid from to phosphoric acid production plant
Heat from natural gas	GJ	189	-
Emission to air			
Water	kg	170	-
Waste to treatment			
Inert waste	kg	3865	landfill of gypsum data from Davis and Haglund

Table 8-11 Production of ammonia

	Unit	Quantity	Comment
Product			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	1000	-
Avoided products			
Heat from natural gas	GJ	1.49	Some energy is recovered during the process
Inputs			
Heat from natural gas	GJ	16.637	34.030 GJ - 17.393 GJ
Natural gas	M^3	591	Feedstock
Electricity	MJ	840	-
Emissions to air			
Carbon dioxide, fossil	kg	1138	CO_2 emissions from fuel incineration are included in the process 'Heat from natural gas'. All CO_2 from feedstock is captured in absorbers and used in Urea making (if applicable). However, ammonia could be also used in other processes where CO_2 cannot be used (in the case it can be vented). Therefore, an input of CO_2 from nature is included in Urea making, to mass balance the CO_2 (no net

		emissions) and ensure that CO_2 emission is accounted for all other cases.

Table 8-12 Production of calcium ammonium nitrate (CAN)

	Unit	Quantity	Comment
Product			
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at plant /RER	kg	1000	-
Inputs			
Ammonium nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	756	-
Limestone	kg	244	-
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	0.732	transport of limestone to plant

Table 8-13: Production of nitric acid

	Unit	Quantity	Comment
Product			
Nitric acid, in water, as 60% HNO_3 (NPK 13.2-0-0), at plant /RER	kg	1000	-
Avoided products			
Heat from natural gas	GJ	1.05	-
Resources from nature			
Oxygen, in air	kg	626	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER E	kg	172	-
De-ionised water	kg	211.4	-
Electricity	MJ	18	-
Emissions to air			
Dinitrogen monoxide	kg	0.42	-
Nitrogen	kg	6.6	-

Table 8-14: Production of ammonium nitrate

	Unit	Quantity	Comment
Product			
Ammonium nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	1000	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER E	kg	219.07	-
Nitric acid, in water, as 60% HNO_3 (NPK 22-0-0), at plant /RER	kg	1312.5	-
Heat from natural gas	GJ	0.7	-
Emissions to air			
Ammonia	kg	6.57	losses due to conversion inefficiency

Water	kg	525	-

Table 8-15: Production of di ammonium phosphate (DAP)

	Unit	Quantity	Comment
Product			
Di ammonium phosphate, as 100% $(NH_3)_2HPO_4$ (NPK 22-57-0), at plant /RER	kg	1000	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	264	stoichiometric ratios
Phosphoric acid, merchant grade (75% H_3PO_4) (NPK 0-54-0), at plant /RER	kg	1050	-
Heat from natural gas	GJ	0.192	Heat from natural gas is used as a proxy for chemical input of natural gas
Heat from natural gas	GJ	0.0525	Heat from natural gas is used as thermal energy input
Electricity	GJ	0.105	-
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	79.2	transport of ammonia to DAP production plant
Emissions to air			
Water	kg	314	-

Table 8-16: Production of Urea

	Unit	Quantity	Comment
Product			
Urea, as 100% $CO(NH_2)_2$ (NPK 46.6-0-0), at plant /RER	kg	1000	-
Resources			
Carbon dioxide, in air	kg	733	From ammonia production, see note in ammonia inventory.
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	567	-
Heat from natural gas	GJ	4.2	-
Emissions to air			
Water	kg	300	-

Table 8-17: Production of triple super phosphate

	Unit	Quantity	Comment
Product			
Triple superphosphate, as 80% $Ca(H_2PO_4)_2$ (NPK 0-48-0), at plant /RER	kg	1000	Remainder is water
Inputs			
Phosphate rock, beneficiated (32% P2O5, 50% CaO), at plant/GLO Economic	kg	450	30% P_2O_5 from rock

Phosphoric acid, merchant grade (75% H_3PO_4) (NPK 0-54-0), at plant /RER	kg	622	70% from acid
Heat from natural gas	GJ	2	energy used in drying, powder production and granulation
Process water	kg	110	dilution of acid
Transport, sea ship, 60000 DWT, 100% F, short, default/GLO	tkm	1665	transport of phosphate rock from western Sahara to port in Europe
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	135	transport of phosphate rock from port to phosphoric acid production plant
Emissions to air			
Water	kg	182	vapor released during drying

Table 8-18: Production of single super phosphate

	Unit	Quantity	Comment
Product			
Single superphosphate, as 35% $Ca(H_2PO_4)_2$ (NPK 0-21-0), at plant /RER	kg	1000	remainder is $CaSO_4$
Inputs			
Phosphate rock, beneficiated (32% P2O5, 50% CaO), at plant/GLO Economic	kg	656.25	-
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	367.5	-
Heat from natural gas	GJ	1.4	-
Transport, sea ship, 60000 DWT, 100%LF, short, default/GLO	tkm	2428.12	Transport of phosphate rock from western Sahara to port in Europe
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	196.88	

Table 8-19: Production of potassium chloride

	Unit	Quantity	Comment
Product			
Potassium chloride (NPK 0-0-60), at mine /RER	kg	1000	-
Inputs			
Potash, as KCl, at mine/GLO Economic	kg	1000	-
Energy, from diesel burned in machinery /RER	GJ	3	-

Table 8-20: Production of potassium sulfate

	Unit	Quantity	Comment
Product			
Potassium sulfate (NPK 0-0-50), Mannheim process, at plant/RER	kg	1000	92% potassium sulfate assume 420 E/t
Hydrochloric acid, 30% HCl, Mannheim process, at plant/RER	kg	1266.667	assume 140 E/t
Inputs			
Potassium chloride (NPK 0-0-60), at mine /RER	kg	833	-

Sulfuric acid (98% H_2SO_4), at plant /RER	kg	570	-
Heat from natural gas	GJ	2.883	-
Electricity mix	GJ	0.217	-
Process water	kg	863.67	used for HCl solution
Transport, freight train, diesel, bulk, 100%LF, flat terrain, default/GLO	tkm	1666	Assumption: all potash is imported from Russia, via rail. 50% electric and 50% diesel
Transport, freight train, electricity, bulk, 100%LF, flat terrain, empty return/GLO	tkm	1666	

Table 8-21: Production of NPK compound

	Unit	Quantity	Comment
Product			
NPK compound (NPK 15-15-15), at plant /RER	kg	1000	-
Inputs			
Potassium chloride (NPK 0-0-60), at mine /RER	kg	250	-
Ammonium Nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	263	-
Di ammonium phosphate, as 100% $(NH_3)_2HPO_4$ (NPK 22-57-0), at plant /RER	kg	263	-
Limestone	kg	224	-

Table 8-22: Production of liquid Urea-ammonium nitrate solution

	Unit	Quantity	Comment
Product			
Liquid Urea-ammonium nitrate solution (NPK 30-0-0), at plant/RER	kg	1000	Solution of Urea and ammonium nitrate in water assume equal ratios by mass
Inputs			
Urea, as 100% $CO(NH_2)_2$ (NPK 46.6-0-0), at plant /RER	kg	366	-
Ammonium Nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), at plant /RER	kg	366	-
Process water	kg	268	-

Table 8-23: Production of PK compound

	Unit	Quantity	Comment
Product			
PK compound (NPK 0-22-22), at plant /RER	kg	1000	-
Inputs			
Triple superphosphate, as 80% $Ca(H_2PO_4)_2$ (NPK 0-48-0), at plant /RER	kg	458	-
Potassium chloride (NPK 0-0-60), at mine /RER	kg	366.7	-
Limestone	kg	175.3	Inert

Table 8-24: Production of ammonium sulfate.

	Unit	Quantity	Comment
Product			
Ammonium sulfate, as 100% $(NH_4)_2SO_4$ (NPK 21-0-0), at plant /RER	kg	1000	-
Inputs			
Ammonia, as 100% NH_3 (NPK 82-0-0), at plant /RER	kg	257.5	-
Transport, truck >20t, EURO4, 80%LF, default {GLO} Economic	tkm	41.27	-
Transport, freight train, electricity, bulk, 50%LF, flat terrain, default {GLO} Economic	tkm	25.36	-
Transport, barge ship, bulk, 5500t, 80%LF, default {GLO} Economic	tkm	33.22	-
Transport, sea ship, 80000 DWT, 80%LF, middle, default {GLO} Economic	tkm	96.79	-
Sulfuric acid (98% H_2SO_4), at plant /RER	kg	742.5	-
Heat from natural gas	GJ	0.8	-

8.3.1 P&K mining

Agri-footprint 8 includes an update in the processes describing mining of phosphorus and potassium used in fertilizer production. This includes the use of mining explosives used for phosphate rock mining, mining unbeneficiated phosphate rock and beneficiating unbeneficiated phosphate rock.

The system boundaries of **unbeneficiated phosphate rock** (raw phosphate rock freshly extracted from the mine) production are from cradle to unbeneficiated phosphate rock. The activities included mining of phosphate rock using blast mining with Ammonium Nitrate Fuel Oil (ANFO). Capital goods, catalysts, and transport are not included. The system boundaries of beneficiated phosphate rock production are from cradle to beneficiated phosphate rock. Included activities are inputs of unbeneficiated phosphate rock, electricity, and fuel. Capital goods, catalysts, and transport are not included. The beneficiated phosphate rock is used as an input for fertilizer production processes requiring phosphate rock. The system boundaries of potash production are from cradle to potash. Included activities are mining of potash. The mined potash is used as an input for the fertilizer production processes that use potassium.

Table 8-25: Unbeneficiated phosphate rock mining.

	Unit	Quantity	Comment
Product			
Phosphate rock, unbeneficiated, at mine/GLO Economic	kg	1,000	-
Inputs			
Blast mining explosives, use of, at mine/RER Economic	kg	0.938	0.7 kg explosive per m3 hard rock (Dyno Nobel, 2010); Bulk density phosphate rock: 1250-1429 kg/m3.
Energy, from diesel burned in machinery/RER Economic	MJ	174.00	The mining operations require an average of 0.174MJ final energy per kg of crude phosphate rock as diesel burned in the machinery. (Issaoui et al, 2022)

Electricity, low voltage {GLO}| market group for electricity, low voltage | Cut-off, S - Copied from ecoinvent	MJ	0.595	The electricity used during the mining operations is marginal (5.95E-04MJ per kg of crude phosphate rock) (Issaoui et al, 2022)
Inert waste {RoW}| market for inert waste | Cut-off, S - Copied from ecoinvent	ton	21.70	1kg crude ore contains an average of 24% P2O5; Industry estimates that 5.2 tons of phosphogypsum is produced for every ton of phosphoric acid. (EPA)
Transformation, from unspecified, natural (non-use)	m2	0.245	Land transformation: 4082 kg crude phosphate rock / m2 /year (Issaoui et al, 2022)
Phosphate ore	ton	1.00	
Transformation, to mineral extraction site	m2	0.245	Land transformation: 4082 kg crude phosphate rock / m2 /year (Issaoui et al, 2022)
Emissions to air			
Particulates, > 10 um	g	50.00	(EEA, 2019)
Total suspended particles	g	102.00	(EEA, 2019)
Particulates, > 2.5 um, and < 10um	g	5.00	(EEA, 2019)
Emissions to water			
Cadmium compounds	mg	3.57	(Issaoui et al, 2022) & EEA, 2019
Uranium	mg	4.74	(Issaoui et al, 2022) & EEA, 2019
Thorium	mg	1.04	(Issaoui et al, 2022) & EEA, 2019

Table 8-26: Unbeneficiated phosphate rock processing into beneficiated phosphate rock.

	Unit	Quantity	Comment
Product			
Phosphate rock, beneficiated (32% P2O5, 50% CaO), at plant/GLO Economic	kg	1.000	-
Inputs			
Phosphate rock, unbeneficiated, at mine/GLO Economic	kg	4.17	1kg crude ore contains an average of 24% P2O5
Electricity, low voltage {GLO}| market group for electricity, low voltage | Cut-off, S - Copied from ecoinvent	MJ	0.041	The total consumption of washing, screening, and flocculation is 0.041MJ of electric energy and 0.0036MJ of diesel per kg of beneficiated phosphate rock
Energy, from diesel burned in machinery/RER Economic	MJ	0.0036	The total consumption of washing, screening, and flocculation is 0.041MJ of electric energy and 0.0036MJ of diesel per kg of beneficiated phosphate rock
Water, unspecified natural origin/m3	l	5.00	

Table 8-27: Mining of potash.

	Unit	Quantity	Comment
Product			
Potash, as KCl, at mine/GLO Economic	kg	1000	-
Inputs			
Electricity, low voltage {GLO}| market group for electricity, low voltage | Cut-off, S - Copied from ecoinvent	kWh	111.00	Chen et al., 2018
Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | Cut-off, S - Copied from ecoinvent	MJ	798.60	36.3 * 22 Chen et al., 2018
Energy, from diesel burned in machinery/RER Economic	MJ	2.83	Proxy for gasoline; 42.5 MJ/kg, 0.75 kg/l. 88.8 ML/ton Chen et al., 2018
Energy, from diesel burned in machinery/RER Economic	MJ	21.80	42.8 MJ/kg, 0.84 kg/l. 607 ML/ton Chen et al., 2018
Inert waste {RoW}| market for inert waste | Cut-off, S - Copied from ecoinvent	g	122.00	
Wastewater, average {RoW}| market for wastewater, average | Cut-off, S - Copied from ecoinvent	l	31.70	
Transformation, from unspecified, natural (non-use)	m2	0.791	Chen et al., 2018
Water, unspecified natural origin/m3	m3	117.00	Chen et al., 2018
Water, unspecified natural origin/m3	m3	7.70	Chen et al., 2018
Sylvinite, in ground	ton	1.35	Between 1.2 and 1.5 ton per ton (Mikkelsen, 2001)
Transformation, to mineral extraction site	m2	0.791	Chen et al., 2018
Emissions to air			
Nitrogen oxides emissions	g	1.58	Chen et al., 2018
Particulates, > 10 um emissions	g	37.00	Chen et al., 2018
Carbon dioxide emissions	kg	48.8	Chen et al., 2018

8.4 Fertilizers market mix

Regionalization of the impact requires the modelling of trade statistics in order to derive the utilization mix in a certain region. We derived the consumption mix based on trades and production statistics from IFA (2026), Eurostat (2021c) and COMtrade (2014-2018). In table 8-28 we can see the proportion that each region imports of each fertilizer, The transport included is regionalized as global.

Table 8-28 Fertilizers products import by different regions.

		Exporter								
Product	**Importer**	**EU**	**CIS**	**Latin America**	**Africa**	**Oceania**	**Middle East**	**East Asia**	**North America**	**South Asia**
Urea (NPK 46.6-0-0)	Europe	75%	11%	1%	8%	0%	3%	1%	1%	0%
	CIS	2%	92%	2%	1%	0%	2%	1%	0%	0%
	Latin America	5%	13%	51%	4%	1%	12%	10%	2%	2%
	Africa	10%	7%	3%	63%	0%	8%	4%	2%	2%
	Oceania	1%	1%	3%	3%	29%	35%	18%	4%	6%
	Middle East	2%	3%	3%	4%	1%	67%	7%	5%	8%
	East Asia	0%	0%	0%	0%	0%	1%	97%	0%	1%
	North America	2%	3%	3%	3%	1%	12%	4%	71%	2%
	South Asia	0%	1%	1%	1%	0%	8%	10%	1%	78%
Ammonium sulfate (NPK 21-0-0)	Europe	91%	5%	0%	1%	0%	0%	2%	0%	0%
	CIS	4%	89%	2%	1%	0%	1%	3%	1%	0%
	Latin America	24%	4%	36%	0%	1%	0%	24%	11%	0%
	Africa	17%	6%	0%	60%	0%	1%	13%	2%	0%
	Oceania	1%	0%	2%	0%	66%	0%	27%	3%	0%
	Middle East	16%	27%	1%	1%	0%	21%	30%	0%	1%
	East Asia	0%	0%	0%	0%	0%	0%	100%	0%	0%

	North America	3%	1%	2%	0%	0%	0%	2%	92%	0%
	South Asia	0%	0%	0%	0%	0%	0%	25%	0%	74%
Ammonium nitrate (NPK 35-0-0)	Europe	97%	3%	0%	0%	0%	0%	0%	0%	0%
	CIS	1%	96%	2%	1%	0%	0%	0%	0%	0%
	Latin America	6%	38%	52%	1%	0%	0%	1%	2%	0%
	Africa	3%	5%	0%	90%	0%	2%	0%	0%	0%
	Oceania	1%	2%	0%	0%	93%	0%	4%	0%	0%
	Middle East	8%	15%	0%	8%	0%	65%	2%	0%	2%
	East Asia	0%	0%	0%	0%	0%	0%	99%	0%	0%
	North America	0%	1%	0%	0%	0%	0%	0%	99%	0%
	South Asia	2%	15%	0%	1%	0%	2%	2%	0%	79%
Calcium ammonium nitrate (NPK 26.5-0-0)	Europe	96%	3%	0%	0%	0%	0%	0%	0%	0%
	CIS	9%	90%	0%	1%	0%	0%	0%	0%	0%
	Latin America	87%	10%	2%	0%	0%	0%	0%	0%	0%
	Africa	20%	5%	0%	65%	0%	7%	2%	0%	0%
	Oceania	78%	3%	0%	0%	3%	1%	15%	0%	0%
	Middle East	8%	2%	0%	4%	0%	86%	0%	0%	0%
	East Asia	0%	0%	0%	0%	0%	0%	100%	0%	0%
	North America	82%	6%	0%	0%	0%	1%	1%	10%	0%
	South Asia	0%	0%	0%	0%	0%	0%	0%	0%	100%
Liquid urea-ammonium nitrate solution (NPK 30-0-0)	Europe	81%	8%	2%	2%	0%	0%	0%	6%	0%
	CIS	2%	94%	1%	0%	0%	0%	0%	3%	0%
	Latin America	23%	12%	38%	1%	0%	0%	2%	25%	0%

	Africa	6%	1%	1%	83%	0%	8%	1%	1%	1%
	Oceania	3%	38%	1%	13%	20%	2%	18%	6%	0%
	Middle East	3%	3%	2%	1%	0%	77%	5%	5%	4%
	East Asia	1%	2%	1%	0%	1%	0%	92%	4%	0%
	North America	10%	13%	4%	1%	0%	0%	1%	71%	0%
	South Asia	0%	0%	0%	0%	1%	0%	22%	1%	76%
NPK compound (NPK 15-15-15)	Europe	65%	29%	1%	2%	0%	1%	2%	0%	0%
	CIS	7%	82%	2%	2%	0%	1%	4%	0%	0%
	Latin America	9%	11%	77%	1%	0%	1%	1%	0%	0%
	Africa	0%	0%	0%	100%	0%	0%	0%	0%	0%
	Oceania	24%	15%	0%	6%	40%	2%	13%	1%	0%
	Middle East	13%	12%	2%	12%	0%	55%	3%	1%	0%
	East Asia	3%	4%	0%	1%	0%	0%	91%	0%	0%
	North America	4%	3%	2%	1%	0%	1%	1%	88%	0%
	South Asia	14%	23%	1%	8%	0%	2%	11%	0%	43%
Di ammonium phosphate (NPK 22-57-0)	Europe	51%	9%	2%	25%	0%	7%	2%	2%	2%
	CIS	7%	63%	2%	8%	1%	3%	7%	5%	4%
	Latin America	4%	5%	31%	9%	1%	4%	12%	30%	3%
	Africa	5%	3%	1%	73%	1%	7%	4%	4%	2%
	Oceania	1%	1%	2%	3%	45%	7%	24%	7%	10%
	Middle East	3%	2%	1%	9%	1%	81%	2%	1%	1%
	East Asia	0%	0%	0%	0%	0%	1%	95%	1%	2%
	North America	1%	2%	3%	3%	1%	1%	4%	82%	2%
	South Asia	2%	2%	1%	4%	2%	12%	28%	3%	46%

8.5 Amino acids from Evonik

Evonik is the only company offering a complete portfolio of the five nutritionally limiting amino acids commonly supplemented in poultry and swine feed. A comparative life cycle analysis of the production of amino acids by Evonik Nutrition & Care GmbH, based on ISO 14040:2006 and 14044:2006, was performed and externally reviewed in 2015 (Evonik Nutrition & Care GmbH, 2015). The GaBi model, used for this study, was converted to SimaPro format in 2019 and the LCI's of the different amino acids are included into Agri-footprint as aggregated system process. As the LCI is a result of a conversion from a GaBi model (Kupfer, 2018), no background data of Agri-footprint was used. [9]

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

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

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

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

Table 8-29: Naming of amino acid products in Agri-footprint.

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

Note that although the amino acids are available in all Agri-footprint libraries, the original data is generated using economic allocation.

[9] Also please be aware that SimaPro and GaBi did not align implementation of impact assessment methods in their software. A process with same substance flows and same impact assessment method applied, could therefore result in different environmental impacts on several impact categories.

9. Data quality ratings

New data quality rating system (DQR) for Agri-footprint will be implemented in the next version, based on the new EF Data Quality Rating rules for datasets that have been developed by the JRC for Environmental Footprint compliant datasets. The Data Quality Rating rules and review requirements for Environmental Footprint datasets (Eynard et. al., 2025) provides quality criteria is a technical report providing the rules for evaluating the Data Quality Rating (DQR) of Environmental Footprint (EF) compliant datasets to update the section on Data Quality of the current Guide for EF compliant data sets (Fazio et al. 2020). The document provides guidance to the dataset developer and reviewer on how to evaluate each data quality criterion.

10. Data limitations of Agri-footprint 8

The data limitations in Agri-footprint are:

- Not all crops possess specific co-product production;
- Currently a default constant value of 400 kg lime per hectare is used for all crops independent of the local soil conditions.
- Seedlings are not included in the inventory, contrary to “start material”. Start material is similar to the product of the inventory and is therefore an adjusted copy of the product LCI. This approach could not be applied for seedlings, since the seedling itself is completely different system as the product itself. Due to the lack of data on seedlings, it was chosen not to model seedlings for all cultivations in the database and hereby the impact of seedling are excluded.
- For ammonia emission modelling for fertilizers, only the “normal pH” scenario is considered. This simplified ammonia might lead to an underestimation of the emitted ammonia, since the “high pH” scenario leads to higher ammonia emissions.
- Heat, electricity or water inputs are not consistently considered by the sources used to model these products.
- The modelling of phosphorus emissions at cultivation is based on a very simple emission model; this may not represent the complexity of reality;
- Pesticide emissions have been modelled using relatively scarce data and simplistic emission modelling, this has impact on all ecotoxicity related impact categories.
- Only a few capital goods are considered in Agri-footprint, in a simplified way:
  - “basic infrastructure” for cultivations
  - “silo” for post-harvest storage
  - “tractor” for energy, from diesel
  - Capital goods in the ecoinvent processes used in Agri-footprint

  All other capital goods that could be used in the Agro-food chain are excluded in Agri-footprint. The exclusion of this leads to an underestimation of impact categories like mineral depletion.
- Capital goods do not include non-basic infrastructure such as administrative buildings, corporate offices, and secondary farm in the life cycle inventories (LCIs) of crop cultivation. ecoinvent processes may include it.
- The loss of moisture during the drying process is not accounted for all grains, pulses and oilseeds. FAOstat yield report is considered already dried to be traded.
- For cooling post-harvest crops, the time spend is not considered, only the energy and the storage space.
- A few processes on market mix and production mix life cycle stages are below the 50% of coverage, these are reported in Appendix XI.

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12. List of tables and figures

12.1 List of tables

Table 2-1 Number of processes included in Agri-footprint (AFP) by version 3
Table 2-2: Table of changes between Agri-footprint 7 and 8..... 4
Table 3-1: Prices used for economic allocation of specific crop groups since Agri-footprint 6.3. 11
Table 3-2: Land use categories description 14
Table 3-3: Fallow land and cropping frequency example 16
Table 3-4: Overview of assumptions in Feedprint cultivation seed production that is applied in Agri-footprint.....20
Table 3-5 Key activity data for roughages 23
Table 3-6: Overview of modelled emissions, literature source and which aspects are included for the calculations 25
Table 3-7: IPCC Tier 1 emission factors and constants. 30
Table 3-8: Heavy metal content of fertilizers.....32
Table 3-9: Heavy metal content of manure 32
Table 3-10: Deposition of heavy metals (Nemecek & Schnetzer, 2012) 33
Table 3-11: Heavy metals in biomass in mg/kg “as is” (Delahaye et al., 2003) 33
Table 3-12 : Heavy metal leaching to groundwater (Nemecek & Schnetzer, 2012).....33
Table 3-13: Update and regionalized substances in Agri-footprint, with Netherlands as an example 37
Table 4-1 Overview of post-harvest activities applied 40
Table 4-2 Electricity and diesel use of nuts used for deriving a nut deshelling default. 41
Table 4-3 Humidity values for crop storage (FAO, *Survey and Analysis of Post-Harvest Losses* (n.d.)). 41
Table 5-1: How the market mix and coverage is estimated, example of Dutch maize (fictive) market mix.....44
Table 5-2: How inventoried products are quantified, production data and ratios used 45
Table 5-3: Transport rules applied per region in the Market mixes. 46
Table 5-4: Total groups production groups and their total mass weight. 47
Table 6-1 Simplified list of processed feed and food products, and the related data source that formed the basis of the inventory.....48
Table 6-2. List of energy sources used based on ecoinvent 52
Table 6-3 Auxiliary material used in various processes, based on background system processes from ecoinvent.....52
Table 6-4. Fish meals and oils from fish reduction.....55
Table 6-5: Edible part and by-products of fish in Agri-footprint, based on FAO (FAO, 2013) 56
Table 6-6: Fish economic, mass and energy allocation. 56
Table 6-7. Important allocation updates in Agri-footprint 7. *) Output value per mass has no consistent unit between processes. It might be for example price in USD/ton, price in EUR/ton but also relative values as communicated by industry experts when actual prices are confidential. Units are always consistent within the process to ensure correct allocation. [1)] USD/ton based on FAOSTAT 5-year average (2014-2018).....61
Table 6-8: Process in- and outputs of oil refining.....63

Table 6-9: Average process in and outputs of oil refining of maize germ oil, rice bran oil, coconut oil, linseed oil. 64
Table 6-10: Key parameters required for mass, energy and economic allocation. 65
Table 6-11: Estimated key parameters required for mass, energy and economic allocation for other refined oils and soap stock. 65
Table 6-12: Key parameters for mass, energy and economic allocation. 65
Table 6-13: Gas emissions from combustion of 280 kg of bagasse 'as is' (wet mass). 70
Table 7-1: Summary of animal production systems/country combinations included in Agri-footprint 6. 71
Table 7-2: Data sources for dairy farm parameters....72
Table 7-3: Herd size at various country dairy farms, and other herd dynamics parameters. .74
Table 7-4: Milk output (and its characteristics) and sold animals at various country dairy farms. 75
Table 7-5: Energy consumption and water use at various country dairy farms. 76
Table 7-6: Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' dairy farms per various feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet. 77
Table 7-7: Manure management system mix and time spend outside for various countries dairy farms. 79
Table 7-8: Inventory for Irish beef production. Data on weights are based on by (Casey & Holden, 2006) and kringloopwijzer. bedding has been taken from kwantitatieve informatie veehouderij (kwin) 2022-2023, water, electricity, and diesel from (Casey & Holden, 2006), and the manure management system is based on (IPCC, 2019a; UNFCC 2023).....81
Table 7-9: Rations for cows and calves per animal for one year – based on (Casey & Holden, 2006).....82
Table 7-10: Compound feed composition (Casey & Holden, 2006). 82
Table 7-11: Nutritional characteristics of the feed ration, based on IPCC (2019B) and Expert Knowledge. 82
Table 7-12: Cow-Calf Herd Parameters per System (Breeding Stage) 84
Table 7-13: Annual Animal Sales and Output Weights per System 84
Table 7-14: Total Feed Intake, Performance Metrics, and Primary Feed Shares per System and Animal Stage (ADG = Average Daily Gain, FCR = Feed Conversion Ratio) 85
Table 7-15: Allocation Parameters for Beef System Outputs 88
Table 7-16: Energy and Bedding Consumption per Livestock Unit (LU) 89
Table 7-17: Data source used for the pig breeding and fattening LCIs. 90
Table 7-18: Piglet breeding and pig fattening animal average population and various population dynamic metrics. 91
Table 7-19: Manure management system mix for various countries pig farms (UNFCCC, 2023) (IPCC, 2019a). 92
Table 7-20: Manure management system mix for pig farms in RNA ((UNFCCC, 2023)& (IPCC, 2019a)).....93
Table 7-7-21: Compound feed formulations, regions and animal type aggregated. 93
Table 7-22: Compound feed formulations, Dutch and animal type specific. Other ingredients have been excluded from the LCI.....94
Table 7-23: Compound Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' swine farms per compound feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet.....94
Table 7-24: Data source used for egg production LCI. 96

Table 7-25: Pullet rearing (<17 weeks) population dynamic metrics (per round). 97
Table 7-26: Laying hens (>17 weeks) population dynamic metrics (per round).....97
Table 7-27: Pullet (<17 weeks) and laying hen (>17 weeks) compound feed formulations. ..98
Table 7-28: Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' poultry farms per various feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet. 98
Table 7-29: Data sources used for the broiler fattening LCI. 99
Table 7-30. Key parameters for the hatchery, Parent rearing and breeding stage for all countries in scope (Per Round). 100
Table 7-31. Key parameters for the broiler Fattening Production SYSTEM (Per round)....101
Table 7-32. Feed rations for parent rearing (broiler parents < 20 weeks), broiler breeding (broiler parents > 20 weeks) and broiler fattening (broilers). 102
Table 7-33: Dry Matter Intake (DMI, kg/animal/year) of the animals on the various countries' poultry farms per various feed fed. Dry matter (DM, %) content and Crude Protein (CP, % of DM) content of the overall diet. 102
Table 7-34: Mass balances of the slaughterhouses for different animal types (Luske & Blonk, 2009). 104
Table 7-35: Energy and water consumption for chicken meat in the slaughterhouse. 104
Table 7-36: Energy and water consumption for pig meat production in the slaughterhouse. 105
Table 7-37: Energy and water consumption for beef in the slaughterhouse. 105
Table 7-38: Key parameters required for economic allocation and allocation based on energy content (Blonk et al., 2007), (Kool et al., 2010). 105
Table 8-1: Primary activity data for the fuel consumption of road transport (Klein et al., 2012b) 107
Table 8-2: Categorized primary activity data for vans, small trucks and large trucks. 107
Table 8-3: Fuel consumption of 5 types of bulk barges and 4 types of container barges. Based on (Den Boer et al., 2008). 108
Table 8-4: Fraction of fuel used for traveling phases for short, middle and long distances for sea ships. 111
Table 8-5 Wagon specifications required to calculate the gross weight of freight trains. 112
Table 8-6: Specification of the airplanes Boeing 747-200F, Boeing 747-400F and Fokker 100. 112
Table 8-7: Fuel consumption of a Boeing 747-200F 113
Table 8-8: Fuel consumption of a Boeing 747-400F 114
Table 8-9: Fuel consumption of a Fokker 100 114
Table 8-10 Inventory for phosphoric acid. 116
Table 8-11 Production of ammonia 116
Table 8-12 Production of calcium ammonium nitrate (CAN) 117
Table 8-13: Production of nitric acid 117
Table 8-14: Production of ammonium nitrate 117
Table 8-15: Production of di ammonium phosphate (DAP) 118
Table 8-16: Production of Urea 118
Table 8-17: Production of triple super phosphate 118
Table 8-18: Production of single super phosphate 119
Table 8-19: Production of potassium chloride 119
Table 8-20: Production of potassium sulfate 119
Table 8-21: Production of NPK compound 120

Table 8-22: Production of liquid Urea-ammonium nitrate solution....120
Table 8-23: Production of PK compound....120
Table 8-24: Production of ammonium sulfate. 120
Table 8-25: Unbeneficiated phosphate rock mining. 121
Table 8-26: Unbeneficiated phosphate rock processing into beneficiated phosphate rock..122
Table 8-27: Mining of potash. 123
Table 8-28 Fertilizers products import by different regions. 124
Table 8-29: Naming of amino acid products in Agri-footprint....127
Table 12-1 Share of active ingredients per pesticide super group [%]. I Herbicide basic cocktail, II Insecticide basic cocktail, III Fungicide basic cocktail. 154
Table 12-2 List of “Not Approved” substances in EU. Status under Status under Reg. (EC) No 1107/2009. 155
Table 12-3 Example of pesticide inventory; Soybeans cultivation in Argentina, based on Agri-footprint 8 pesticide modelling. 156
Table 12-4: Summary of state-level crop cultivation data sources 168
Table 12-5. *Manure Nutrients (N and P) by State from EPA (2023a) for Relevant States.*..170
Table 12-6. Share of Manured Acres by Crop. 171
Table 12-7. Product Properties for Allocation. 172
Table 12-8. Allocation Factors for Products and Co-Products for the three Allocation Methods (Economic, Energy, and Mass)....172
Table 12-9: Products with a Market Mix coverage lower than 50%. 176
Table 12-10: Products with a Production Mix coverage lower than 50%. 176

12.2 List of figures

Figure 1: General agri-food supply chain representative of most Agri-footprint life-cycle stages. Indicated are also the chapters of reference for the data description. 2
Figure 2: Product, Co-product and Inputs for an Agri-footprint 8 cultivation LCI of Wheat cultivation in Germany as shown in SimaPro. 8
Figure 3: Outputs for an Agri-footprint 8 cultivation LCI of Wheat cultivation in Germany as shown in SimaPro. 9
Figure 4: Multiple cropping in Argentina (2 crops/ha/yr) (Argentina Soybean Area, Yield and Production). 15
Figure 5: Nitrous oxide emission (direct and indirect) from due to different N inputs (IPCC, 2019b)....26
Figure 6: Emission factors for ammonia emissions from fertilizers (g NH3/kg N applied) (European Environment Agency, 2016). 31
Figure 7: Emissions from drained peatland include CO_2, CH_4 and N_2O (Cao, P. et al. 2026). 36
Figure 8: IPCC Equation 5.2 Adjusted daily emission factor (Tier 1)....38
Figure 10: Sankey representation of how market mixes are calculated in Agri-footprint....44
Figure 11: Generic transport model from a central hub in land of cultivation to the market location within a specific country. 46
Figure 12: Wet milling of maize (van Zeist et al., 2012f). 57
Figure 13: Diagram describing the process of production of rice without husks and rice husks from a rice dry milling process. 58

Figure 14: Diagram describing the process of production of white rice, rice husks, rice bran, and rice brokens from a rice dry milling process in China. 59
Figure 15: Lupin protein-concentrate production process (Van Veghel, 2017). 67
Figure 16: Soy protein-concentrate production process (Van Veghel, 2017). 67
Figure 17: Pea protein-concentrate production process (Van Veghel, 2017). 67
Figure 18: Soy protein-isolate production process (Van Veghel, 2017).....68
Figure 19: Lupin protein-isolate production process (Van Veghel, 2017). 68
Figure 20: Pea protein-isolate production process (Van Veghel, 2017). 69
Figure 21: Product flow diagram for fertilizer production. The colored lines indicate specific intermediate flows (see legend). Raw materials are listed on the top of the figure, N fertilizers are listed on the left, P fertilizers on the bottom, K fertilizers on the right. Figure based on description in Kongshaug (1998). 115

Appendix I Crops Yield

Sources that provided the yield of non-FAOstat crops:

Iso 2 Country code	Crop name	Source
ES	Grass (16% DM)	Eurostat
BE - DE - FR - GB - IE - IT - NL - PL	Grass (16% DM)	Smit, H. J., Metzger, M. J., & Ewert, F. (2008). Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems, 98(3), 208-219. https://doi.org/10.1016/j.agsy.2008.07.004
DE	Maize forage	Smit, H. J., Metzger, M. J., & Ewert, F. (2008). Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems, 98(3), 208-219. https://doi.org/10.1016/j.agsy.2008.07.004
AU - NZ	Grass (16% DM)	Aden, N., Change, C., Farm, F., Barron, N., & Shannon, M. (2015). Grassland Production & Utilisation
ES - IT	Lucerne	Eurostad 2014-2018
DK - IT	Maize forage	Eurostad 2014-2018
NL	Lucerne	Phosphorus and Potassium Fertilization of Alfalfa. Sofia Lissbrant, W. Kess Berg, Jeffrey Volenec, Sylvie Brouder, Brad Joern, Suzanne Cunningham, and Keith Johnson. 2009
US	Maize forage	Corn for Silage Area Harvested, Yield, and Production – States and United States: 2018-2020. Crop Production 2020 Summary (January 2021). USDA, National Agricultural Statistics Service
NZ	Maize forage	NEW ZEALAND SURVEY OF MAIZE AREAS AND VOLUMES: JUNE 1, 2024 ISSN: 2744-5755
US	Grass (16% DM)	USDA, National Agricultural Statistics Service, 2017. Data for hay.
US	Lucerne	USDA, National Agricultural Statistics Service, 2017. Data for hay.
NL	Fodder beet	Fodder Beet. Growers Guideline. Field Options Performance Seeds. 2019.1

Appendix II Crop Properties

Properties such as dry matter content (DM) and gross energy content (GE) have great influence on the environmental impact of crops. The detailed value used are based on a fresh matter, and they are listed here:

Crop name	Gross Energy (Mj/kg)	Dry Matter (kg/kg)	Source
Almonds, with shell	26.19	0.96	USDA (2024)
Anise	14.00	0.91	Pimpinella anisum (PROSEA).
Apples	2.59	0.15	USDA (2024)
Apricots	2.01	0.12	USDA (2024)
Artichokes	2.62	0.14	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Asparagus	1.17	0.07	USDA (2024)
Avocados	9.33	0.33	USDA (2024)
Bananas	4.10	0.25	USDA (2024)
Barley grain	16.01	0.87	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Beans, dry	14.43	0.88	USDA (2024)
Beans, green	1.67	0.10	USDA (2024)
Blueberries	2.68	0.16	USDA (2024)
Broad beans	18.70	0.87	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Buckwheat grain	14.90	0.87	USDA (2024)
Cabbages	1.30	0.08	USDA (2024)
Canary seed	16.69	0.92	Canaryseed Development Commission of Saskatchewan (2016); and Comparative nutritional analysis of domestic and imported commercial canary egg food and mixed seeds based diets (2023).
Carobs	17.40	0.85	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Carrots and turnips	2.01	0.12	USDA (2024)
Cashew nuts, with shell	23.64	0.95	USDA (2024)
Cassava	6.72	0.40	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Cauliflowers and broccoli	1.17	0.07	USDA (2024)
Chestnut	8.20	0.48	João Santos et al. (2022)
Chick peas	16.02	0.91	USDA (2024)
Chicory roots	0.71	0.05	Perović et al. (2021)
Chillies and peppers, green	1.21	0.08	USDA (2024)
Cinnamon	10.04	0.89	Food Standards Australia New Zealand. (2025).
Cloves	13.89	0.90	Food Standards Australia New Zealand. (2025).
Cocoa, beans	24.86	0.93	Niikoi Kotey et al. (2022)
Coconuts	13.96	0.51	Food Standards Australia New Zealand. (2025).
Coffee, green	14.05	0.90	Degefa et al. (2022); and Şemen et al. (2017)

Cranberries	2.97	0.13	Food Standards Australia New Zealand. (2025).
Cucumbers and gherkins	0.67	0.04	USDA (2024)
Currants	1.91	0.17	Food Standards Australia New Zealand. (2025).
Dates	17.60	0.84	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Eggplants	1.09	0.07	USDA (2024)
Figs	3.55	0.21	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Fodder beet	2.92	0.18	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Garlic	5.98	0.37	USDA (2024)
Ginger	4.30	0.27	Food Standards Australia New Zealand. (2025).
Grapefruit	2.90	0.16	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Grapes	3.35	0.20	USDA (2024)
Grass (16% DM)	3.80	0.16	Shackleton et al. (2024); Doyle et al. (1997); and Tas (2005).
Groundnuts, with shell	23.72	0.94	Balasubramanian et al. (2024)
Hazelnuts, with shell	26.82	0.96	USDA (2024)
Hempseed	26.20	0.91	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Hops	4.30	0.25	Rossini et al. (2020); and Maye (2024)
Kiwi fruit	2.68	0.16	USDA (2024)
Leeks	1.84	0.13	USDA (2024)
Lemons and limes	2.90	0.16	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Lentils	15.06	0.91	USDA (2024)
Lettuce and chicory	0.71	0.05	USDA (2024)
Linseed	27.10	0.92	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Lucerne	5.40	0.30	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Lupins	11.82	0.92	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Maize	16.14	0.86	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Maize forage	4.24	0.23	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Mangoes	3.26	0.17	USDA (2024)
Melons	1.59	0.10	USDA (2024)
Millet grain	14.13	0.90	USDA (2024)
Mustard seed	20.21	0.94	Stojanović et al. (2023)
Nutmeg	20.90	0.94	Food Standards Australia New Zealand. (2025).
Oat grain	14.33	0.90	USDA (2024)
Oil palm fruit	6.30	0.37	Iqbal et al. (2019); Mohammed et al. (2022); Sehgal & Sharma (2021); and Hardon, Rajanaidu & van der Vossen (2001).
Olives	5.90	0.23	USDA (2024)
Onions, dry	1.51	0.09	USDA (2024)

Oranges	2.18	0.13	USDA (2024)
Papayas	1.40	0.08	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Peaches and nectarines	1.92	0.12	USDA (2024)
Pears	2.68	0.16	USDA (2024)
Peas, dry	18.30	0.87	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Peas, green	3.11	0.23	Food Standards Australia New Zealand. (2025).
Pepper	11.56	0.88	Food Standards Australia New Zealand. (2025).
Peppermint	2.25	0.16	Food Standards Australia New Zealand. (2025).
Pigeon peas	18.70	0.89	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Pineapples	2.51	0.15	USDA (2024)
Pistachios	25.02	0.96	USDA (2024)
Plums and sloes	2.47	0.15	USDA (2024)
Poppy seed	21.25	0.94	Melo et al. (2022)
Potatoes	3.46	0.21	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Rapeseed	26.58	0.92	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Raspberries	2.38	0.14	USDA (2024)
Rice	15.02	0.89	USDA (2024)
Rye grain	15.59	0.87	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Safflower seed	26.10	0.95	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Seed cotton	21.97	0.92	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Sesame seed	29.10	0.97	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Sorghum grain	15.61	0.89	USDA (2024)
Soybeans	23.60	0.89	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Spinach	1.17	0.08	USDA (2024)
Sugar beet	3.18	0.19	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Sugar cane	4.91	0.27	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Sunflower seed	24.24	0.95	USDA (2024)
Sweet potatoes	3.58	0.21	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Tangerines	2.90	0.16	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Taro	2.23	0.12	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Tea	10.15	0.89	Uba et al. (2022); and Özyılmaz & Genç (2019)
Tomatoes	0.92	0.05	USDA (2024)
Triticale grain	13.61	0.90	Food Standards Australia New Zealand. (2025).
Vanilla	13.89	0.90	Food Standards Australia New Zealand. (2025).

Vegetables, fresh nes	2.13	0.15	USDA (2024)
Vetches	3.59	0.19	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Walnuts, with shell	31.00	0.95	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)
Watermelons	1.00	0.07	USDA (2024)
Wheat grain	15.83	0.87	Heuzé, Tran, Bastianelli, Archimede & Sauvant (2016)

The crop "**Vegetables fresh**, **nes**" refers to vegetables fresh.

Appendix III Crop classification

For the land occupation, there are 2 different crop classifications: Temporary and Permanent, the *temporary* crops analyzed are:

Anise; Artichokes; Asparagus; Bananas; Beans, green; Cabbages; Carobs; Carrots and turnips; Cassava; Cauliflowers and broccoli; Chicory roots; Chillies and peppers, green ; Cucumbers and gherkins; Eggplants; Fodder beet; Garlic; Ginger; Leeks; Lettuce and chicory; Maize forage; Melons; Peas, green; Pepper; Peppermint; Pineapples; Pumpkins, squash and gourds; Quinoa grain; Spinach; Sugar beet; Sugar cane; Tomatoes; Vegetables, fresh nes; Watermelons; Yams; Barley grain; ; Beans, dry; Broad beans; Groundnuts, with shell; Mustard seed; Potatoes; Rice; Seed cotton; Sesame seed; Sorghum grain; Triticale grain; Lentils; Maize; Onions, dry; Pigeon peas; Soybeans; Sunflower seed; Buckwheat grain; Canary seed; Chick peas; Hempseed; Linseed; Millet grain; Oat grain; Poppy seed; Rapeseed; Rye grain; Safflower seed; Sweet potatoes; Taro; Vetches and Wheat grain.

The *permanent* crops analyzed are:

Almonds, with shell; Apples; Apricots; Avocados; Blueberries; Cashew nuts, with shell; Chestnut; Cinnamon; Cloves; Cocoa, beans; Coconuts; Coffee, green; Cranberries; Currants; Dates; Figs; Grapefruit; Grapes; Grass (16% DM); Hazelnuts, with shell; Hops; Kiwi fruit; Lemons and limes; Lucerne; Mangoes; Nutmeg; Oil palm fruit; Olives; Oranges; Papayas; Peaches and nectarines; Pears; Pistachios; Plums and sloes; Raspberries; Tangerines; Tea; Vanilla and Walnuts, with shell.

Appendix IV Seeds/Starting Material

Average seed used as Starting material list.

Crop name	Average Seed (kg/ha)	Sources name
Anise	0.001986	FAOSTAT
Bambara beans	67.54163	FAOSTAT
Barley grain	187.133	FAOSTAT
Beans, dry	44.83346	FAOSTAT
Beans, green	44.83346	FAOSTAT
Broad beans	92.11619	FAOSTAT
Buckwheat grain	69.02206	FAOSTAT
Cabbages	0.35	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Canary seed	10.95565	FAOSTAT
Carrots and turnips	2.897991	FAOSTAT
Cassava	1.560174	FAOSTAT
Castor oil seed	9.375503	FAOSTAT
Cauliflowers and broccoli	1.25	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Chick peas	40.83975	FAOSTAT
Chicory roots	5	Brian Dear NSW Department of Primary Industries. Brett Upjohn, NSW Department of Primary Industries. Andrew Craig, SARDI. April 2007
Coconuts	13.80985	FAOSTAT
Fodder beet	3.5	FODDER BEET, GROWERS GUIDELINES 2019. in UK. Www.field-options.co.uk
Fodder potatoes	1751.086	Smit, H. J., Metzger, M. J., & Ewert, F. (2008). Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems, 98(3), 208-219. https://doi.org/10.1016/j.agsy.2008.07.004
Garlic	0.61203	FAOSTAT
Grass (16% DM)	6	Smit, H. J., Metzger, M. J., & Ewert, F. (2008). Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems, 98(3), 208-219. https://doi.org/10.1016/j.agsy.2008.07.004
Groundnuts, with shell	77.73012	FAOSTAT
Hempseed	39.84326	FAOSTAT
Lentils	48.733	FAOSTAT
Linseed	58.32056	FAOSTAT
Lucerne	8	PGG Wrightson Seeds. Lucerner Management Guide. 2023. pggwrightsonseeds.com
Lupins	68.38005	FAOSTAT
Maize	38.5662	FAOSTAT
Maize forage	37.74446	Corn for Silage Area Harvested, Yield, and Production – States and United States: 2018-2020. Crop Production 2020 Summary (January 2021). USDA, National Agricultural Statistics Service
Maize, green	38.5662	FAOSTAT
Millet grain	20.48107	FAOSTAT
Mustard seed	19.68685	FAOSTAT
Nuts, nes	0.034536	FAOSTAT

Oat grain	264.252	FAOSTAT
Oil palm fruit	0.932575	FAOSTAT
Okra	1.89	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Onions, dry	2.5	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Peas, dry	159.5133	FAOSTAT
Peas, green	159.5133	FAOSTAT
Pigeon peas	20.85654	FAOSTAT
Poppy seed	2.20165	FAOSTAT
Potatoes	1751.086	FAOSTAT
Rapeseed	15.7641	FAOSTAT
Rice	111.6384	FAOSTAT
Rye grain	217.6682	FAOSTAT
Safflower seed	21.22887	FAOSTAT
Seed cotton	25	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Sesame seed	11.53946	FAOSTAT
Sorghum grain	19.98629	FAOSTAT
Soybeans	67.30486	FAOSTAT
Spices, nes	0.015572	FAOSTAT
Spinach	38.666	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Sugar beet	21	FAOSTAT Land & Water (2001).
Sugar cane	1277.141	FAOSTAT
Sunflower seed	28.49561	FAOSTAT
Sweet potatoes	112.0379	FAOSTAT
Taro	31.61351	FAOSTAT
Triticale grain	170.6979	FAOSTAT
Vegetables, fresh nes	0.651248	FAOSTAT
Vetches	86.22309	FAOSTAT
Watermelons	9.12	WIKIFARMER SINGLE MEMBER PRIVATE COMPANY. 2017-2026. https://wikifarmer.com
Wheat grain	156.9183	FAOSTAT
Yautia	353.9184	FAOSTAT

Appendix V Pesticide Model

Scope / limitations of the inventory

The scope / limitations of this inventory are:

- The inventory provides is on a crop-country level (e.g. soybean cultivation in Brazil).
- The pesticides used for seed treatment, crop storage / transport and soil disinfection were not included. The focus is on pesticides use in crop cultivation.
- The location, technique of application and timing of application is not taken into account. These factors can be highly significant for emissions to various environmental compartments and are hence important for ecotoxicity impact scores. However, due to the complexity (and uncertainties) involved in modelling these impacts, average conditions are taken into account in standard impact assessment methods such as ReCiPe.
- The Emissions compartment methodology used was developed in 2014, in following versions of Agri-footprint, other methodologies for missions compartments calculations will be analysed.
- Only the categories of “herbicide”, “insecticide” and “fungicides and bactericides” applications were considered. Other phytosanitary measures, as rodenticides or mineral oil applications are outside the scope of this inventory.
- Basic active ingredient mixes were defined for herbicide, insecticide and fungicide (H/I/F) respectively based on top 80% active ingredient use per H/I/F group in Netherlands, France and United States of America.
- No tropical countries are represented in the creation of herbicide, insecticide and fungicide (H/I/F) mixes.
- The same active ingredient mix of each pesticide type is used for all crops and countries considering only differences for the EU region, where certain active ingredients are not allowed. Other regions/countries banned products will be considered on future versions.
- Scientific studies will be included in future Agri-footprint versions, the case of “*Environmental performance assessment of global crop protection practice*” (Zhang, Y) that has not been published yet.

Inventory development process

Agri-footprint 8 modelling of pesticide use per crop/country (kg a.i/ ha) follows the steps described below.

Step 1: FAOstat country use data per supergroup

Herbicides, insecticides and fungicides are the three large pesticide supergroups covered in Agri-footprint 8. In section we refer generally as pesticide supergroup to these three pesticide categories.

The first step on the inventory development was to obtain country specific data for total pesticide supergroup active ingredient use per year. FAOstat compiles national statistics on total herbicide, total insecticide and total fungicide use in ton of active ingredient per year (FAO, 2026c)(FAO, 2026c). FAO pesticide use statistics were implemented considering a five-year average from 2019 to 2023.

Step 2: Pesticide application per supergroup per crop

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

First, the total active ingredient used per supergroup (ton/year) was distributed per crop based on the share of the annual harvested area of each crop to the total national harvested area. This was done using FAOstat data on ha crop/year considering a five-year average from 2019 to 2023.

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

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

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

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

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

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

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

To establish the active substance base cocktail for each super group, we turned again to France (AGRESTE, 2018), The Netherlands (CBS, 2018) and the United States (USDA-NASS, 2019b) national inventory statistics. No tropical countries are included in this data collection; other sources will be consulted to expand the total data reference that we can use to improve the substance cocktail for each super group in future versions of Agri-footprint.

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

Once a preliminary cocktail for each super group was defined, the active substances have to be matched with substances and characterization factors in SimaPro. For all herbicide active substances, a SimaPro equivalent name with a characterization factor was found, for Fungicide active substances, only sulfur had no characterized equivalent and was taken from the final mix, for insecticides, spinosad, flonicamid, spirotetramat, sulfur, tefluthrin and chlorantraniliprole, were not fond appropriate SimaPro equivalents with a characterization factor. Small percentages of each active substance were used, so it was decided not to make any replacement or use other substances as proxies.

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

The resulting default cocktails are shown in Table 12-1 for each pesticide supergroup.

Table 12-1 Share of active ingredients per pesticide super group [%]. I Herbicide basic cocktail, II Insecticide basic cocktail, III Fungicide basic cocktail.

Active ingredients	Share for Herbicides I	Share for Herbicides I for EU countries
Glyphosate	43%	61%
Metolachlor, (S)	15%	0
Prosulfocarb	7%	10%
Metamitron	6%	8%
Pendimethalin	5%	7%
Aclonifen	4%	6%
Diquat dibromide	3%	0
Atrazine	3%	0
Chloridazon	2%	0
Isoproturon	2%	0
Terbuthylazin	1%	1%
Ethofumesate	1%	1%
Metribuzin	1%	0
2,4-D	1%	1%
Linuron	1%	0
Metazachlor	1%	1%
Napropamide	1%	1%
Chlorpropham	1%	0
2-Methyl-4-chlorophenoxyacetic acid	1%	1%

Active ingredients	Share for Insecticides II	Share for Insecticides II for EU countries
Chlorpyrifos	26%	0%
Pirimicarb	14%	58%
Ethoprop	9%	0%
Acephate	8%	0%

Bifenthrin	7%	0%
Methiocarb	7%	0%
Lambda-cyhalothrin	5%	21%
Oxamyl	5%	0%
Indoxacarb	3%	0%
Cypermethrin	3%	13%
Pyriproxyfen	2%	8%
Methomyl	2%	0%
Imidacloprid	2%	0%
Propargite	2%	0%
Carbaryl	2%	0%

Active ingredients	Share for Fungicides III	Share for Fungicides III for EU countries
Mancozeb	55%	0%
Chlorothalonil	15%	0%
Captan	9%	33%
Propamocarb	7%	26%
Copper, ion	5%	19%
Tebuconazole	2%	7%
Maneb	2%	0%
Azoxystrobin	2%	7%
Folpet	2%	7%
Propiconazole	1%	0%
Epoxiconazole	1%	0%

For European countries, EU restrictions are considered (European Commission, 2025), and the following chemical active substances were excluded, re-adjusting the rest of the mix per supergroup to 100%.

Table 12-2 List of "Not Approved" substances in EU. Status under Status under Reg. (EC) No 1107/2009.

Region	Super group	Restricted active ingredients
EU	Fungicide	Mancozeb
EU	Fungicide	Chlorothalonil
EU	Fungicide	Maneb
EU	Fungicide	Propiconazole
EU	Fungicide	Epoxiconazole
EU	Herbicide	Metolachlor, (S)
EU	Herbicide	Diquat dibromide
EU	Herbicide	Atrazine
EU	Herbicide	Chloridazon
EU	Herbicide	Isoproturon
EU	Herbicide	Metribuzin
EU	Herbicide	Linuron
EU	Herbicide	Chlorpropham
EU	Insecticide	Chlorpyrifos

EU	Insecticide	Ethoprop
EU	Insecticide	Acephate
EU	Insecticide	Bifenthrin
EU	Insecticide	Methiocarb
EU	Insecticide	Oxamyl
EU	Insecticide	Indoxacarb
EU	Insecticide	Methomyl
EU	Insecticide	Imidacloprid
EU	Insecticide	Propargite
EU	Insecticide	Carbaryl

Emission compartments

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

- 90% to agricultural topsoil
- 1% to fresh water
- 9% to air

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

Table 12-3 Example of pesticide inventory; Soybeans cultivation in Argentina, based on Agri-footprint 8 pesticide modelling.

Type of pesticide	Name	Application rate (kg a.i. per ha)
Fungicide	Mancozeb	0.0203
Fungicide	Chlorothalonil	0.0055
Fungicide	Captan	0.0033
Fungicide	Propamocarb	0.0026
Fungicide	Copper, ion	0.0019
Fungicide	Tebuconazole	0.0007
Fungicide	Maneb	0.0007
Fungicide	Azoxystrobin	0.0007
Fungicide	Folpet	0.0007
Fungicide	Propiconazole	0.0004
Fungicide	Epoxiconazole	0.0004
Insecticide	Chlorpyrifos	0.0151
Insecticide	Pirimicarb	0.0082
Insecticide	Ethoprop	0.0052
Insecticide	Acephate	0.0047

Insecticide	Bifenthrin	0.0040
Insecticide	Methiocarb	0.0040
Insecticide	Lambda-cyhalothrin	0.0029
Insecticide	Oxamyl	0.0029
Insecticide	Indoxacarb	0.0017
Insecticide	Cypermethrin	0.0017
Insecticide	Pyriproxyfen	0.0012
Insecticide	Methomyl	0.0012
Insecticide	Imidacloprid	0.0012
Insecticide	Propargite	0.0012
Insecticide	Carbaryl	0.0012
Herbicide	Glyphosate	3.2064
Herbicide	Metolachlor, (S)	1.1171
Herbicide	Prosulfocarb	0.5210
Herbicide	Metamitron	0.4458
Herbicide	Pendimethalin	0.3706
Herbicide	Aclonifen	0.3008
Herbicide	Diquat dibromide	0.2256
Herbicide	Atrazine	0.2256
Herbicide	Chloridazon	0.1504
Herbicide	Isoproturon	0.1504
Herbicide	Terbuthylazin	0.0752
Herbicide	Ethofumesate	0.0752
Herbicide	Metribuzin	0.0752
Herbicide	2,4-D	0.0752
Herbicide	Linuron	0.0752
Herbicide	Metazachlor	0.0752
Herbicide	Napropamide	0.0752
Herbicide	Chlorpropham	0.0752
Herbicide	2-Methyl-4-chlorophenoxyacetic acid	0.0752

Appendix VI Peat Crop-Groups

On this list you may find the crop-groups used by Cao, P. et al. (2026) in the "*Spatially explicit global assessment of cropland greenhouse gras emissions circa 2020*" study, and the crops used in Agri-footprint 8 alignment.

Crop categories (CAO et al. 2026)	AFP8 crop name
Wheat	Wheat,
Rice	Rice,
Maize	Maize (corn),
Barley	Barley,
Pearl Millet	Millet,
Small Millet	Millet,
Sorghum	Sorghum,
Other Cereals	Cereals n.e.c., Teff, Rye, Oats, Buckwheat, Triticale, Canary seed, Mixed grain,
Potato	Potatoes,
Sweet Potato	Sweet potatoes,
Yams	Yams,
Cassava	Cassava, fresh, Cassava, dry,
Other Roots	Taro, Yautia, Edible roots and tubers with high starch or inulin content, n.e.c., fresh,
Bean	Beans, dry,
Chickpea	Chick peas, dry,
Cowpea	Cow peas, dry,
Pigeon Pea	Pigeon peas, dry,
Lentil	Lentils, dry,
Other Pulses	Broad beans and horse beans, dry, Peas, dry, Bambara beans, dry, Vetches, Lupins, Other pulses n.e.c.,
Soybean	Soya beans,
Groundnut	Groundnuts, excluding shelled,
Coconut	Coconuts, in shell,
Oil Palm	Oil palm fruit,
Sunflower	Sunflower seed,
Rapeseed	Rape or colza seed, Mustard seed,
Sesame Seed	Sesame seed,
Other Oil Crops	Olives, Linseed, Karite nuts (sheanuts), Castor oil seeds, Tung nuts, Safflower seed, Poppy seed, Hempseed, Other oil seeds, n.e.c.,
Sugarcane	Sugar cane,
Sugarbeet	Sugar beet,
Cotton Seed	Seed cotton, unginned,
Cotton	Seed cotton, unginned,
Other Fibre Crops	Jute, raw or retted, Abaca, manila hemp, raw, Flax, raw or retted, Kenaf, and other textile bast fibres, raw or retted, Ramie, raw or retted, Sisal, raw, Coir, raw, Cotton lint, ginned,
Arabic Coffee	Coffee, green,
Robust Coffee	Coffee, green,
Cocoa	Cocoa beans,
Tea	Tea leaves,
Tobacco	Unmanufactured tobacco,

Banana	Bananas,
Plantain	Plantains and cooking bananas,
Citrus	Oranges, Tangerines, mandarins, clementines, Lemons and limes, Pomelos and grapefruits, Other citrus fruit, n.e.c.,
Other Tropical Fruit	Papayas, Watermelons, Cantaloupes and other melons, Figs, Mangoes, guavas and mangosteens, Avocados, Pineapples, Dates, Persimmons, Cashewapple, Other tropical fruits, n.e.c.,
Temperate Fruit	Apples, Pears, Quinces, Apricots, Sour cherries, Peaches and nectarines, Plums and sloes, Raspberries, Gooseberries, Currants, Blueberries, Cranberries, Grapes, Kiwi fruit, Other fruits, n.e.c., Other stone fruits, Other pome fruits,
Tomato	Tomatoes,
Onion	Onions and shallots, dry (excluding dehydrated), Onions and shallots, green,
Other Vegetables	Cabbages, Artichokes, Asparagus, Lettuce and chicory, Spinach, Cauliflowers and broccoli, Cucumbers and gherkins, Eggplants (aubergines), Chillies and peppers, green (Capsicum spp. and Pimenta spp.), Green garlic, Leeks and other alliaceous vegetables, Other beans, green, Peas, green, Broad beans and horse beans, green, Carrots and turnips, Okra, Green corn (maize), Other vegetables, fresh n.e.c., Chicory roots, Locust beans (carobs),
Rubber	Natural rubber in primary forms,
Rest of Crops	Other sugar crops n.e.c., Other stimulant, spice and aromatic crops, n.e.c., Cashew nuts, in shell, Chestnuts, in shell, Almonds, in shell, Walnuts, in shell, Pistachios, in shell, Kola nuts, Hazelnuts, in shell, Areca nuts, Maté leaves, Hop cones, Pepper (Piper spp.), raw, Chillies and peppers, dry (Capsicum spp., Pimenta spp.), raw, Vanilla, raw, Cinnamon and cinnamon-tree flowers, raw, Cloves (whole stems), raw, Nutmeg, mace, cardamoms, raw, Anise, badian, coriander, cumin, caraway, fennel and juniper berries, raw, Ginger, raw, Peppermint, spearmint, Pyrethrum, dried flowers, Grass, Maize forage.
Country average	Country average

Appendix VII List of crop and country combinations

Table VII-1:List of crops and countries combinations in Agri-footprint 8.

Crop	Countries
Barley grain	AR, AT, AU, BE, BG, BR, CA, CH, CN, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, JP, LT, LV, NL, NO, NZ, PL, PT, RO, RU, SE, SI, SK, TH, UA, US, BY, CL, DZ, EG, IN, IR, MA, MX, TR, ZA, KZ, ET, SY, AZ, UY, IQ, TN, RS, KG, HR, SA, PE, MD, TJ, MK, TM
Beans, dry	AR, CA, CN, ET, FR, GR, IE, IT, NL, PL, RO, US, ZA, IN, BR, MM, MX, KE, UG, BI, RW, MZ, CM, AO, CD, TR, BY, KZ, MW, TG, NI, ID, AU, GH, EG, VN, IR, GT, HN, VE, BO, SV, CO, KG, TH, PE, HT, KH, BD, MG, CU, UA, ZM, JP, PY, DO, CI, PH, TJ, SO, AL
Broad beans	DE, FR, GB, AU, IT, LT, PL, CN, ET, SD, EG, PE, LV, DK, TN, MA, SE, IE, DZ, MX, EE, GT, ES, SY, FI, IR, AR, PY, AT, BO, DO, BR, RO, GR, TR, RU
Chick peas	AR, AU, IN, RU, TR, US, CA, MX, MM, ET, IR, SD, MA, SY, YE, DZ
Groundnuts, with shell	AR, CN, AU, BR, EG, IN, SD, SN, TH, TR, UG, US, VN, ZA, ID, MX, IR, MA, NG, MM, GN, CM, GH, CF, CD, MW, CI, AO, NI, BJ, ZM, ET, MZ, PK, SL, ZW, BD, MG, GM, TG, LA
Linseed	AR, AT, BE, BG, BY, CA, CN, CZ, DE, DK, ES, FR, GB, HU, IN, IT, LT, LV, PL, RO, RU, SE, SK, UA, US, AU, CL, EG, KZ, MX, ET, NP, UY, BR
Lupins	AU, DE, ES, FR, IT, PL, RU, MA, CL, ZA, GR, PE, UA, BY
Maize	AR, AT, BE, BG, BR, BY, CA, CH, CN, CZ, DE, ES, FR, GR, HU, IN, IT, JP, LT, NL, PL, PT, RO, RU, SI, SK, TH, TR, UA, US, ZA, ID, MX, PH, PK, VN, AU, BD, CL, DZ, EG, IR, KR, MA, MY, GE, NG, ET, RS, PY, UG, MW, KE, GH, AO, ZM, NP, CD, MM, CM, VE, HR, GT, MZ, BJ, CO, PE, MD, EC, CI, ZW, BO, KZ, BA, KH, TG, GN, SV, SN, KG
Mustard seed	CA, CZ, DE, RU, UA, US, CN, NP, MM, KZ
Oat grain	AT, AU, BE, BG, BR, CA, CH, CL, CN, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, JP, LT, LV, NL, NO, PL, PT, RO, RU, SE, SI, SK, UA, US, AR, BY, MA, MX, TR, ZA, KZ, DZ, HR, ET, RS, BA, UY, AL
Peas, dry	AT, AU, BE, BG, BR, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, PL, RO, RU, SE, SI, SK, UA, US, IN, ET, AR, KZ, BY, PE, CO, MW, MM, NZ, MD, MA, MG, TM, RW, BI, UG, TJ, DZ
Potatoes	AT, BE, BG, CA, CH, CY, CZ, DE, DK, EE, EG, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, NO, PL, PT, RO, SE, SI, SK, TR, US, CN, IN, RU, AR, BR, BY, CL, ID, IR, JP, MA, MX, PH, TH, UA, VN, ZA, BD, PK, PE, DZ, ET, NP, CO, KZ, KE, MW, AU, KG, BO, NG, TJ, AZ, RW, LB, RS, SY, GT, TM, SA, KR, ZW, SD, IL, NZ, AO, VE, MZ, MM, TN, IQ, BI, AM, GN, UG, LY, BA, CM, YE, EC, AL
Rapeseed	AR, AT, AU, BE, BG, BR, CA, CH, CN, CZ, DE, DK, EE, ES, FI, FR, GB, HU, IE, IN, IT, JP, LT, LV, NL, NO, PL, RO, RU, SE, SI, SK, UA, US, BY, CL, MA, MX, TR, ZA, PK, BD, IR, UY, KZ, MD
Rice	BG, CN, ES, FR, GR, HU, IN, IT, KH, PK, PT, RO, RU, TH, TR, UA, US, AR, BR, EG, MM, UY, VN, AU, CI, CL, CM, GH, GN, ID, IQ, IR, JP, KE, KR, MA, MX, MY, MZ, PH, SL, SN, BD, NG, NP, LK, MG, LA, PE, CO, CD, EC, PY, GY, DO, VE, BO, KZ, NI, BJ
Rye grain	AT, BE, BG, BY, CA, CH, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LT, LV, NL, NO, PL, PT, RO, RU, SE, SK, UA, US, AR, AU, BR, CL, CN, EG, MA, MX, TR, ZA, KZ, RS
Seed cotton	US, AU, BR, CN, EG, ID, IN, IR, MX, TR, VN, ZA, PK, UZ, GR, AR, BJ, TM, CM, CI, TJ, KZ, AZ, MM, SD, NG, ET, ZW, UG, SY, ES, BD, KG
Sesame seed	IN, MX, PK, TR, BO, CN, EG, ET, IR, MA, NG, PY, SD, TH, UG, VN, MM, CF, BR, MZ, CM, SN, GT, BD, YE, VE, SO, KH, KR, BJ, LA, LK, SY

Sorghum grain	AR, AU, BR, CN, EG, FR, IN, IT, RU, UA, US, ZA, MX, MA, NG, ET, SD, CM, BO, GH, SN, TG, UG, KE, YE, RW, MM, MZ, BJ, OM, MW, SA, HU, SV, ZW, UY, SO, PY, PK, CI, GN, SL, BW, NI, TH
Soybeans	AR, AT, BG, BR, CA, CH, CN, CZ, DE, EG, ES, FR, GR, HU, IN, IT, JP, PL, PY, RO, RU, SI, SK, TH, TR, UA, US, VN, MX, AU, ID, IR, KR, ZA, GE, BO, UY, NG, RS, ZM, BJ, MW, KZ, HR
Sunflower seed	AR, AT, AU, BG, BR, CA, CH, CL, CN, CZ, DE, ES, FR, GR, HU, IN, IT, PL, RO, RU, SK, TH, TR, UA, US, EG, BY, IR, MA, MX, ZA, KZ, MD, RS, UG, MM, BO, HR, PK, SD, ZM
Triticale grain	AT, BE, BG, CH, CZ, DE, DK, EE, ES, FR, GB, HU, LT, LV, NL, PL, PT, RO, SE, SI, SK, AU, BR, BY, CA, CL, CN, MX, RU, TR, RS, IT, HR, BA, GR, UA
Wheat grain	AR, AT, AU, BE, BG, BR, CA, CH, CN, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IN, IT, JP, LT, LV, MX, NL, NO, PK, PL, PT, RO, RU, SE, SI, SK, TH, TR, UA, US, BY, CL, DZ, EG, IR, KR, MA, TN, ZA, KZ, ET, IQ, RS, SY, NP, AZ, TM, MD, PY, BD, UY, HR, TJ, SA
Beans, green	DE, EG, ES, FR, KE, MA, NL, CA, CL, CN, GB, ID, IN, IR, IT, NZ, PH, TH, TR, UA, US, ZA, BD, LK, DZ, BE, PL, GT, SY, GR, AU, RS, TJ, GH, RO, SN, SA, EC, PE
Cabbages	ES, NL, BD, BY, CA, CL, CN, DE, EG, FR, GB, ID, IN, IR, IT, JP, MA, MX, NZ, PH, PL, RO, RU, TH, TR, UA, US, VN, ZA, KR, ET, KE, UZ, ZW, KZ, AO, MW, PT, RS, MK, SN, DZ, KG, AZ, BE, TJ, LK, VE, MY, HN, GT, NI, AU, AM, AL, TM, RW, CM, AT, GR, SY, CU, LB, BA, IL, LT, JO, HU, CZ, CO, DO, JM, BG
Carrots and turnips	BE, NL, BY, CA, CL, CN, DE, EG, ES, FR, GB, ID, IR, IT, JP, MA, MX, NZ, PH, PL, RU, TR, UA, US, ZA, IN, KZ, DZ, TJ, AU, AR, CO, NG, VE, PE, TN, IL, KG, KE, PT, AT, SE, GT, RO, KR, ZW, DK, BO, LK, HU, FI, TM, MN, CH, IE, DO, NO, RS, SD, RW, EC, LT, AZ, LY, BD, CZ, JM, SA, ET, SN
Cassava	BR, CR, IN, TH, VN, AR, CN, ID, MX, MY, PH, NG, CD, GH, KH, AO, CI, MZ, CM, MW, BJ, LA, ZM, PY, BI, GN, MG, SL, UG, CG, PE, RW, SN, TG, CF, CO, KE, CU, HT, LR, VE, LK, MM
Cauliflowers and broccoli	ES, FR, NL, CA, CL, CN, EG, GB, ID, IN, IR, IT, JP, MA, MX, NZ, PH, RU, TH, TR, UA, US, VN, ZA, BD, DZ, PL, EC, AU, BE, DE, GT, PE, JO, PT, GR, RO, SY, CO, IL, VE, OM, SA, LB
Chicory roots	BE, NL
Grass (16% DM)	BE, BR, DE, DK, ES, FR, GB, IE, IT, NL, NZ, PL, US
Lentils	AU, CA, CN, TR, US, IN, NP, BD, RU, ET, KZ, SY, IR, AR, MA, DZ
Lucerne	ES, IT, US, DK
Maize forage	BE, BR, DE, DK, FR, IT, NL, NZ, PL, US
Onions, dry	FR, BD, BY, CN, DE, EG, ES, ID, IN, IR, IT, JP, MA, MX, NL, PH, PL, RU, TR, UA, US, VN, DZ, SD, BR, NG, KR, UZ, MM, KZ, ZA, CO, AR, TJ, PE, SN, CL, ET, CM, GB, UG, MZ, AZ, AU, MW, CA, SA, YE, ZW, KG, LY, RO, TN, VE, BE, GT, KE, AT, GH, LB, GR, BO, AL, JO, TM, LK, BJ, IL, SY, DO, SE, PT, MK, CD, IQ, CU
Peas, green	AT, BE, DE, EG, ES, FR, GB, MA, NL, ZA, BG, BY, CA, CH, CL, CN, CZ, DK, EE, FI, GR, HU, IN, IR, IT, JP, LT, MX, NZ, PH, PL, PT, RO, RU, SE, SI, SK, TH, TR, UA, US, DZ, PE, KE, TN, GT, AR, AU, RS, BO, SY
Pigeon peas	IN, MW, MM, KE, DO, NP, HT, UG
Spinach	BE, NL, CA, CN, DE, EG, ES, FR, ID, IR, IT, JP, MX, NZ, PH, TR, US, KE, MY, GR, BD, KR
Sugar beet	AT, BE, CH, CL, CZ, DE, DK, ES, FI, FR, GB, HU, IT, LT, NL, PL, RO, RU, SE, SK, UA, US, BY, CA, CN, EG, GR, IR, JP, MA, MX, TR, RS, HR
Sugar cane	AR, AU, BR, CN, CO, EG, ID, IN, MX, PK, SD, TH, US, VE, BD, CR, CU, GT, IR, JP, MA, MY, PE, PH, VN, ZA, MM, BO, EC, SV, NI, KE, PY, ZW, UG, SZ, DO, HN, ZM, NP, MG, MW, MZ, CD, PA, CI, BZ, FJ, HT
Almonds, with shell	US, AU, ES, IT, TR, MA, IR, SY, CN, TN, DZ, CL, PT, LY, GR, YE, LB
Coconuts	ID, IN, PH, BD, CI, CN, MX, TH, VN, BR, LK, PG, MM, MY, GH, DO, VU, MZ, NG, VE, CO, JM, KE, KH, SV, MG, TO, WS, GN
Oil palm fruit	BR, ID, MY, TH, CN, HN, MX, PG, PH, CO, NG, GT, CI, EC, CM, CD, GH, CR, PE, NI, GA

Fodder beet	NL
Anise	EG, IN, RU, SY, TR, MX, IR, CN, MA, VN, KE, CA, TN, AR
Apples	AR, AU, BE, BR, BY, CA, CL, CN, DE, EG, ES, FR, GR, IN, IR, IT, JP, MA, MX, NL, NZ, PL, PT, RO, RU, TR, UA, US, ZA, DZ, MD, GB, KR, RS, HU, AZ, SY, KZ, TJ, AT, LB, CH, KG, BA, PE, TN, CZ, MK, AL, IL
Apricots	AR, AU, CA, CL, CN, EG, ES, FR, GR, IN, IR, IT, JP, MA, MX, NZ, RU, TR, UA, US, ZA, UZ, DZ, TJ, AM, SY, TN, RS, TM, IQ, AZ, LY, KG, RO, KZ, LB, JO, HU, BG, MD, CH, AT, IL
Artichokes	CL, CN, EG, ES, FR, IR, MA, MX, TR, US, IT, DZ, PE, AR, TN, GR, SY
Asparagus	CA, CL, CN, IR, JP, MA, MX, NL, NZ, PE, PH, TH, TR, US, DE, ES, IT, FR, PL
Avocados	AR, AU, BR, CL, CN, ID, IL, MA, MX, NZ, PE, PH, TR, US, ZA, CO, DO, KE, ET, HT, VN, VE, GT, MW, ES, ZW, CM, CD, LB, CI, SV, EC, MG, PT, LK, PY, CR, BO, GR
Bananas	AR, AU, BD, BR, CI, CN, CO, CR, EC, EG, ES, ID, IN, IR, JP, MA, MX, PA, PH, TH, US, VN, AO, GT, PE, RW, KE, DO, PG, BI, ET, SD, CM, MW, TR, CD, LA, HN, VE, MZ, ZA, MG, KH, MY, NP, BO, ZW, HT, GN, CU, IL, LR, YE, GH
Blueberries	CA, CL, ES, MA, MX, NL, NZ, PE, RU, UA, US, PL, AU, PT, DE, IT, FR
Buckwheat grain	BR, BY, CA, CN, JP, RU, UA, US, ZA, KZ, NP
Canary seed	AR, AU, CA, MX, TR, TH, UY
Carobs	MA, UA, TR, LB, DZ, TN, IL
Cashew nuts, with shell	BR, IN, VN, CI, PH, BJ, ID, GH, MZ, NG, GN, CO, TH, LK, GM, MY, KE
Chestnut	CN, ES, BO, TR, KR, IT, PT, GR, JP, FR
Chillies and peppers, green	CL, CN, EG, FR, GR, ID, IN, IR, IT, JP, MA, MX, PH, TH, TR, UA, US, NL, ES, IL, NG, DZ, TN, ET, PL, KZ, KR, MK, PE, VE, AR, RO, RS, GH, BJ, CO, NP, OM, AL, JO, HU, LK, GT, SY, DO, CU, CM, BG, AZ, PT, SL, BA, SD, IQ, MY, ZW, CI, LY
Cinnamon	ID, VN, CN, LK, MG
Cloves	ID, MG, KM, LK, KE
Cocoa, beans	CI, CM, DO, EC, GH, NG, ID, BR, PE, CO, PG, UG, CD, MX, VE, IN, SL, GN, LR, TG, MG, GT, CG
Coffee, green	BR, CO, HN, ID, UG, VN, ET, PE, IN, CF, GN, GT, MX, LA, NI, CN, CR, CI, PH, CD, VE, MG, PG, KE, SV, CM, YE, BO, RW, TG, TH, DO, BI, MW
Cranberries	CA, UA, US
Cucumbers and gherkins	BD, BY, CA, CL, CN, EG, ID, IN, IR, JP, MA, MX, MY, PH, RU, TH, TR, UA, US, ZA, DE, NL, ES, KZ, PL, KR, CM, AZ, SD, TJ, DZ, FR, SA, IQ, JO, SY, GR, LB, KG, AL, RO, OM, IL, CU, AU, TN, IT, FI, BG, KW, AM, GB, PE, MK
Currants	AU, JP, NL, NZ, PL, RU, UA, GB, DE, FR, AT, LT, HU, AZ, FI, DK
Dates	CN, DZ, IL, IR, MA, MX, TN, US, EG, SA, IQ, PK, SD, OM, LY, KW, YE, JO
Eggplants	CN, EG, FR, ID, IN, IR, IT, JP, MA, MX, PH, TH, TR, UA, US, NL, ES, BD, DZ, IQ, SY, LK, KZ, CI, SA, SD, AZ, RW, RO, JO, LB, AM, GH, GR
Figs	AR, AU, BR, CN, EG, IN, IR, IT, JP, MA, MX, TR, US, ZA, DZ, ES, SY, TN, AL, GR, AZ, LY, IQ, FR, PT, LB, PE, CO, IL, BA
Garlic	AR, BY, CL, EG, ES, ID, IN, IR, IT, JP, MA, MX, NZ, PH, RO, RU, TH, TR, UA, US, CN, BD, KR, ET, UZ, MM, DZ, BR, PE, NP, KG, KZ, SY, GT, SD, FR, AZ, TN, PL
Ginger	CN, IN, NG, PE, NP, ID, TH, CM, LK, GY, PH, KR, MY, ET
Grapefruit	AR, AU, BR, CN, EG, ES, IR, MA, MX, NZ, PH, TH, TR, US, VN, ZA, SD, SY, IL, TN, BD, SZ, JM, HT, CI, HN, BS, CR, MY, CY, MG, CU, ZW, CD, FR, LB, MZ, VE
Grapes	AR, AU, BR, CA, CL, CN, EG, ES, FR, GR, IN, IR, IT, JP, MA, MX, NZ, PH, RU, TH, TR, UA, US, ZA, DE, PT, RO, PE, DZ, MD, HU, IQ, TM, AT, GE, MK, TJ, AM, SY, AZ, AL, KR, BG, RS, TN, YE, LB, CH, HR, SA, UY, SI, KZ
Hazelnuts, with shell	IT, TR, US, AZ, CL, GE, CN, IR, FR, PL, ES, RS, KG, GR
Hempseed	CL, RU, TR, UA

Hops	DE, US, ET, CN, CZ, PL, SI, AL, GB, ES, NZ, FR, JP, AU, AR, ZA
Kiwi fruit	AU, CL, FR, GR, IR, IT, JP, NZ, TR, US, CN, PT, ES
Leeks	BE, CN, DE, ES, FR, ID, IR, MA, MX, NL, PH, PL, TR, KR, KZ, GB, LK, AL, PT, PE, GR, IT, CH, UZ, AT, ET
Lemons and limes	AR, AU, BR, CL, CN, EG, ES, IN, IR, IT, JP, MA, MX, NZ, PH, TH, TR, US, ZA, CO, SD, PE, SY, GT, DZ, VE, GR, BD, KE, LB, SA, IL, ZW, UY, TN, DO, NP, GH, JO, CR, BO, HN, YE, PT, EC, JM, LY, MW, SV, MY, FR, SO
Lettuce and chicory	CA, CL, CN, DE, EG, ES, FR, IN, IR, IT, JP, MA, MX, NL, NZ, TH, TR, UA, US, ZA, BE, CO, AU, GB, KR, GT, TN, VE, PE, PL, PT, GR, CH, SY, JO, AT, IQ, SE, AL, LB, NO, SA
Mangoes	AR, AU, BR, CN, EG, ID, IN, IR, JP, MA, MX, PE, PH, TH, US, VN, ZA, BD, MW, NG, KE, SD, CO, NP, HT, YE, CD, MG, CU, GN, CI, GT, LK, ET, VE, SN, ZW, EC, GH, SA, MY, KH, DO
Melons	AR, AU, BD, BR, CA, CL, CN, CR, EG, ES, FR, ID, IN, IR, IT, JP, MA, MX, NZ, PH, TR, UA, US, ZA, KZ, GT, HN, KR, IQ, VE, TN, SY, AZ, CO, JO, GR, PT, RO, SA, AL, CU, CM, OM, YE, SD, DO, PY, IL, SN
Millet grain	AR, AU, CN, IN, IR, JP, MA, MX, RU, TR, UA, US, ZA, NG, SD, ET, SN, NP, GH, GN, MM, CM, KE, UG, CI, YE, MW, AO, CD, ZW, GM, KZ, SL, ZM
Nutmeg	GT, ID, IN, NP, LA, LK, BT, GD
Olives	AR, AU, CL, EG, ES, FR, GR, IR, IT, MA, MX, TR, US, TN, PT, DZ, SY, PE, JO, LY, LB, AL, IL
Oranges	AR, AU, BR, CL, CN, EG, ES, ID, IN, IR, IT, JP, MA, MX, MY, NZ, PH, RU, TH, TR, US, VN, ZA, DZ, GR, GH, CO, PE, SY, TN, VE, PT, HN, PY, CR, BO, SD, CD, ZW, EC, IQ, GN, GT, KE, YE, NI, UY, DO, MW, IL, LB, MG, JM, HT, MZ, KH, SV, BZ, ET, SN
Papayas	AR, AU, BR, CL, CN, ID, IN, IR, MA, MX, PH, TH, US, ZA, DO, NG, CD, PE, CO, VE, BD, VN, CU, KE, GT, ET, GY, MW, MY, CR, EC, MZ, LA, YE, HT, BO, NP
Peaches and nectarines	AR, AU, BR, CA, CL, CN, EG, ES, FR, IR, IT, JP, MA, MX, NZ, RU, TR, UA, US, ZA, GR, KR, DZ, TN, IN, JO, LB, BO, AM, VE, IL, RS, SY, GT, PE, AZ, PT, TJ, TM, GE, CO, BG
Pears	AR, AU, BR, BY, CA, CL, CN, DE, EG, ES, FR, IN, IR, IT, JP, MA, MX, NL, NZ, PL, PT, RO, RU, TR, UA, US, ZA, BE, KR, DZ, GR, AZ, RS, AT, BA, LB, CH, CO, NP, IL, GB, HU
Pepper	BR, IN, VN
Peppermint	MA, AR
Pineapples	AR, AU, BR, CN, CR, ID, IN, JP, MX, PH, TH, US, VN, ZA, NG, CO, GH, AO, PE, DO, VE, BJ, MY, MW, GT, CM, KE, EC, BD, CD, HN, PA, MG, BO, PY, LA, NI, GN, MZ, LK, JM, SZ, CI
Pistachios	US, IR, TR, CN, SY, MG, TN
Plums and sloes	AR, AU, BY, CA, CL, CN, EG, ES, IR, JP, MA, MX, NZ, RO, RU, TR, UA, US, ZA, RS, BA, IT, FR, MD, PL, DZ, IN, BG, LY, KR, DE, AL, AZ, HU, TM, MK, AM, SY, LB, GE, GR, PT, IL, TN, CO, IQ, KG, AT
Poppy seed	TR, RS
Raspberries	AU, CA, ES, MA, MX, NL, NZ, PL, PT, RU, UA, US, RS, GB, BA, CL, AZ, DE, BG, MD, FR, CH, KG, IT, NO, BE
Safflower seed	AR, AU, CN, IN, IR, KZ, MX, RU, TR, US, KG, ET, UZ, TJ
Sweet potatoes	AR, BD, BR, CL, CN, EG, ID, IN, JP, MA, MX, MY, PH, US, VN, ZA, MW, NG, AO, ET, RW, UG, MG, BI, KE, PG, CD, CM, MZ, GN, KR, CU, PE, SD, SL, ZW, ZM, GH, LA, HT, SN, AU, UY
Tangerines	AR, AU, BR, CN, EG, ES, IR, IT, JP, MA, MX, NZ, PE, PH, TH, TR, US, ZA, KR, DZ, CO, MW, BO, NP, IL, GR, SY, VE, UY, TN, GE, AZ, HR, FR
Taro	CN, EG, JP, PH, TH, NG, CM, GH, PG, MG, RW, GN, BI, CI, GA, CD, CF, LR
Tea	CN, ID, IN, IR, KE, LK, MW, VN, TR, BD, UG, AR, JP, RW, NP, MM, TH, ET
Tomatoes	BD, BY, CA, CL, CN, EG, ID, IN, IR, JP, MA, MX, PH, RU, TH, TR, UA, US, ZA, NL, ES, FR, IT, PL, BR, NG, DZ, PT, TN, AR, MZ, CM, GR, CO, KZ, AZ, SY, MW,

	KE, IQ, SD, AO, JO, SA, TJ, GT, ZW, RO, GH, AU, KR, TM, IL, AL, CU, BE, BJ, OM, DO, KG, LB, LY, PE, MY, VE, AM, HU, SN, MK, YE, BG, RS, DE, ET, RW
Vanilla	MG, ID, MX, PG, CN, TR, TO, UG
Vegetables, fresh nes	BD, BR, BY, CA, CL, CN, EG, ID, IN, IR, JP, MA, MX, NL, NZ, PH, RU, TH, TR, UA, US, VN, ZA, NG, NP, MM, KR, LA, DZ, UG, AR, CM, KE, KH, CU, BA, BI, ET, MY, CD, MG, ZM, OM, SL, TJ, PG, ZW, SD, GB, AO, FR, MW, MZ, SN, AU, BJ, AM, CO, SY, GT, CI, IL, TG, ES, KG
Vetches	BY, ET, MX, TR, TN, MA, UA, EG, RU, SY
Walnuts, with shell	CL, ES, FR, GR, IT, RO, US, CN, IR, TR, IN, MX, EG, AR, MD, BY, MA, AZ, AU, SY, BA, NP, RS, PL, GE, PT, KG, HU
Watermelons	AR, AU, BR, CA, CL, CN, CR, EG, ES, ID, IN, IR, JP, MA, MX, MY, NZ, PH, RU, TH, TR, UA, US, VN, ZA, DZ, SN, KZ, TJ, IT, SA, DO, TM, KR, TN, GR, AZ, IQ, KE, SY, AL, RO, LY, CO, KG, SD, YE, VE, RS, LA, HU, PE, GT, AM, MK, PY, IL, JO, CM, BG

Appendix VIII Water management regimes ratios

The proportions of water management regimes extracted from IFPRI (2024), for each country, are applied to the specific harvested area, allowing us to obtain the specific spatial distribution for these ecosystems in each country.

Country name	Ratio irrigated Continuous flooded rice area	Ratio irrigated multiple drainage	Ratio irrigated single drainage	Ratio rainfed Drought prone	Ratio rainfed deep water rice area	Ratio rainfed regular rainfed rice area	Ratio rain feed upland
Argentina	0.975	0	0.025	0	0	0.998	0.002
Australia	0.662	0.212	0.126	0	0	1	0
Bangladesh	0.042	0.955	0.003	0.336	0.251	0.291	0.123
Benin	0.662	0.212	0.126	0	0	0.696	0.304
Bolivia (Plurinational State of)	0.662	0.212	0.126	0.01	0	0.01	0.98
Brazil	0.751	0	0.249	0.017	0	0.001	0.982
Bulgaria	0.662	0.212	0.126	0.991	0	0.009	0
Cambodia	0.975	0.001	0.025	0.614	0.163	0.201	0.022
Cameroon	0.662	0.212	0.126	0.22	0	0.04	0.739
Chile	1	0	0	0.092	0	0.406	0.502
China	0.2	0.8	0	0.572	0.003	0.143	0.282
Colombia	0.341	0.33	0.329	0.027	0	0.836	0.136
Côte D'Ivoire	0.662	0.212	0.126	0.322	0	0.018	0.66
Democratic Republic of the Congo	0.662	0.212	0.126	0.174	0	0	0.826
Dominican Republic	0.662	0.212	0.126				
Ecuador	0.662	0.212	0.126	0.039	0	0.037	0.924
Egypt	0.662	0.212	0.126				
France				0.000636	6.5E-05	0.998461	0.000838
Ghana	0	0	1	0.905	0	0.02	0.075
Greece	0.663	0.212	0.125	0.414	0	0.586	0
Guinea	0.662	0.212	0.126	0.001	0.051	0.115	0.833
Guyana	0.662	0.212	0.126	0.143	0	0.712	0.145
Hungary				0.999556	0	0.000444	0
India	0.355	0.279	0.367	0.45	0.097	0.165	0.288
Indonesia	0.43	0.35	0.22	0.295	0.4	0.105	0.2
Iran (Islamic Republic Of)	0.662	0.212	0.126	0.868	0	0.132	0
Iraq	0.662	0.212	0.126	1	0	0	0
Italy	0.662	0.212	0.126	0	0	1	0
Japan	0.09	0.91	0	0	0	1	0
Kazakhstan	0.662	0.212	0.126	0.998	0	0.001	0.001
Kenya	0.662	0.212	0.126	0.464	0	0.042	0.494

Lao People's Democratic Republic	0.678	0.203	0.12	0.782	0.106	0.005	0.107
Madagascar	0.662	0.212	0.126	0.823	0.04	0.017	0.12
Malaysia	1	0	0	0.575	0.001	0.064	0.359
Mexico	1	0	0	0.046	0	0.046	0.909
Morocco	0.662	0.212	0.126				
Mozambique	0.662	0.212	0.126	0.659	0	0.009	0.332
Myanmar	0.003	0.997	0	0.667	0.13	0.152	0.052
Nepal	0.653	0.214	0.132	0.619	0.014	0.252	0.116
Nicaragua	0.662	0.212	0.126	0.017	0	0.017	0.966
Nigeria	0.662	0.212	0.126	0	0	0.696	0.304
Pakistan	0.002	0.001	0.997	0.641	0.063	0.108	0.188
Paraguay	0.664	0.211	0.125	0.007	0	0.652	0.341
Peru	0.662	0.212	0.126	0.454	0	0.029	0.517
Philippines	1	0	0	0.684	0	0.257	0.059
Portugal	0.662	0.212	0.126	0.996	0	0.001	0.002
Republic Of Korea	0.15	0.85	0	0.857	0	0.048	0.095
Romania	0.662	0.212	0.126	1	0	0	0
Russian Federation	0.659	0.217	0.125	0.982	0	0.007	0.011
Senegal	0.668	0.208	0.123	0	0.187	0.452	0.361
Sierra Leone	0.662	0.212	0.126	0	0.072	0.435	0.493
Spain	0.662	0.212	0.126	0.309	0.031	0.262	0.398
Sri Lanka	0.662	0.212	0.126	0.933	0	0.033	0.033
Thailand	0.999	0.001	0	0.737	0.037	0.201	0.025
Türkiye	0.662	0.212	0.126	0.996	0	0.004	0
Ukraine	0.662	0.212	0.126	1	0	0	0
United States of America	0.98	0.02	0				
Uruguay	0.662	0.211	0.126	0.002	0	0.862	0.136
Venezuela (Bolivarian Republic Of)	0.662	0.212	0.126	0.327	0	0.344	0.329
Viet Nam	0.645	0.007	0.347	0.564	0.125	0.187	0.123

Appendix IX Regionalized US product footprint datasets for common feed ingredients

This appendix contains the documentation of the data and life cycle assessment (LCA) methodology taken to construct state-level US cultivation environmental footprint datasets. State-level cultivation datasets were created for maize, soybeans, winter wheat, spring wheat, and sorghum.

1. Cultivation Modelling

The goal for this modelling project includes generating datasets representing U.S. state-level cultivation of corn, soybeans, wheat (winter and spring varieties), and sorghum. Activity data were collected from the USDA National Agricultural Statistical Service (NASS) Quick Stats tool across the 2018 to 2024 production year window for yield, annual irrigation application per acre, annual N, P, and K fertilizer applications per acre and percent of acreage treated, annual pesticide active ingredient applications per acre and percent of acreage treated, and energy use (from diesel and electricity) for irrigation pumping. However, due to the staggered, periodic nature of USDA NASS survey programs, the specific years that data are available vary by crop and parameter. In general, our modelling averaged seven years of yield data and at least 2 years of other key parameters (fertilizer, pesticide and irrigation rates) for each crop and each represented state. We feel that this approach is an appropriate compromise within the limitations of available survey data: averaging additional years of yield data is beneficial in offsetting fluctuations due to seasonal differences, and key parameters are averaged across at least 2 years while balancing the age of data (e.g., including more than 2 years of data for fertilizer application rate would require including data more than 10 years old).

State-level cultivation data were collected to build representative models for the top-producing states needed to collectively capture at least 95% of total US production for each crop. Winter wheat was an exception, as complete data was only available[1] for 91% of US production.

It is helpful to understand the broader structure of USDA National Agricultural Statistics Service data gathering efforts. The Census of Agriculture is a comprehensive survey of all US agriculture that occurs every 5 years. There are additional survey programs focusing on particular aspects or crops that occur more frequently, but on staggered calendar years. For example, the Agricultural Chemical Use Program surveyed chemical (including fertilizers) use for corn in 2018 & 2021, soybeans in 2018, 2020 & 2023, and sorghum in 2019 & 2024 (https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/index.php). County Agricultural Production Surveys collect acreage and production data (and therefore yield) annually for selected crops in key states.

All of the NASS data (census and various surveys) is aggregated and accessible via the USDA QuickStats interface. The staggered and inconsistent (across different crops) nature of the specific year that a given datapoint is available makes generalized summaries of these data somewhat confusing. The important piece to communicate is that - over the 2018 - 2024 time period selected, at least 2 years of data were available for all key datapoints. If additional years were available for a given crop over this time period, these datapoints were included in the average.

USDA NASS includes data on crop-specific irrigation data only in Census years (2018 and 2023). NASS also includes at least 2 years of state-level fertilizer application rate and pesticide

application rate data for each crop in scope. However, the specific years of these NASS surveys varies by crop (i.e., survey efforts are offset such that not all crops are surveyed in the same year). In order to capture inter-annual variability of these important variables, datasets were comprised of averages of all available annual data points from 2018-2024.

Energy required for irrigation is only available as cost *per irrigated acre* within a state (not crop specific); localized energy prices were used to convert cost to physical units. Utilizing this data requires an assumption that all crops within the state have the same irrigation energy demands per irrigated acre, an acknowledged limitation. However, crop-specific data on acres irrigated (and therefore fraction of total acres for a given crop within the state) were available, and this fraction is used to distribute or "average" the impacts of irrigation from "irrigated acres" to "total harvested acres (by crop)" within a state.

Additional input data regarding seeding rate and field operation diesel use were collected from state and crop specific enterprise budgets[2] available from Cooperative Extension Services, affiliated with Land Grant Universities within each state where cultivation occurs. For states where enterprise budgets were available for multiple regions, an average value was calculated for each variable. For states where enterprise budgets were available for multiple different cultivation practices, the budget that most closely resembled data collected from NASS (i.e. yield, irrigation, etc.) was selected. In cases where enterprise budgets were not available for a specific state, neighboring states with similar climates, practices and yields were used as proxy. Data sources are summarized in Table 12-4.

Table 12-4: Summary of state-level crop cultivation data sources

Parameter	Unit	Years Available	Source	Data Granularity
Yield	bu/ac	2018-2024 (7 years averaged)	USDA NASS	State and crop specific
Irrigation rate	ac ft/ac	2018, 2023	USDA NASS	State and crop specific
Irrigated acres harvested	acres	2018,2022-2023	USDA NASS	State and crop specific
Total acres harvested	acres	2018,2022-2023	USDA NASS	State and crop specific
Nitrogen fertilizer application rate*	lb/ac	at least 2 years per crop over 2018-2024 time period	USDA NASS	State and crop specific
Phosphate fertilizer application rate*	lb/ac	at least 2 years per crop over 2018-2024 time period	USDA NASS	State and crop specific
Potassium fertilizer application rate*	lb/ac	at least 2 years per crop over 2018-2024 time period	USDA NASS	State and crop specific
Organic fertilizer application (manure N & P)	kg/ha	2017	EPA and ERS	state and crop specific estimates
Red-dyed diesel price	$/gal	2018,2022-2023	US EIA	State specific
Electricity price- industrial	$/kWh	2018,2022-2023	US EIA	State specific
Fungicide application rate*	lb a.i./ac	at least 2 years per crop over 2018-2024 time period	USDA NASS	State and crop specific

Herbicide application rate*	lb a.i./ac	at least 2 years per crop over 2018-2024 time period	USDA NASS	State and crop specific
Insecticide application rate*	lb a.i./ac	at least 2 years per crop over 2018-2024 time period	USDA NASS	State and crop specific
Seeding rate	seeds/ac	2019/2022/2023/2024	Crop Enterprise Budgets	State and crop specific
Field operation fuel use	gal/ac	2019/2022/2023/2024	Crop Enterprise Budgets	State and crop specific

* These rates were derived by combining USDA NASS statistics on average application rate per treated acres per year with percentage of planted acres treated, for each crop/state combination.

2. Land Use Change

Land use change emissions were calculated following PAS 2050-1 methodology (BSI, 2012). Land use (forest, grassland, pasture, cropland) in each state was gathered for the years 2000 and 2020. Land use data for the US were based on GIS generated state-level land cover datasets aggregated by Li et al. (2023). Differences between these years were considered land transformation. Direct land use change (LUC) emissions from changes in carbon stocks associated with these land transformations were then allocated to those crops that have expanded in land area over the time period. State-level harvested area of each crop was sourced from USDA NASS for the same time period. Amortization of LUC emissions following the PAS 2050-1 guidance applies equal distribution of emissions over the 20-year look-back time window.

3. Peat Oxidation Emissions

The US Environmental Protection Agency (EPA) produces annual reports that tracts national GHG emissions for the US called the “National Inventory Report” or “Inventory of US Greenhouse Gas Emissions and Sinks” that includes data on cropland on drained organic soils (peatlands). To provide a more granular inventory that states can use, the EPA also publishes a complementary state-level dataset: US EPA’s 2023 State GHG Emissions and Removals report (EPA, 2023b). Total state-level CO2 emissions from cropland on drained organic soils were sourced from the state-level EPA dataset (EPA, 2023b) from “cropland remaining cropland” category and “organic soils” carbon pool. These values were then divided by total harvested cropland in each state sourced from NASS. Since the EPA report only accounts for CO2 emissions, methane (CH4) and nitrous oxide (N_2O) emissions were estimated for each state based on the ratio of agricultural emissions (CO2, CH4, and N2O) from drained organic soils from FAOSTAT at the national level. State-level peat oxidation emissions were adjusted further to better represent distinctions between crops by applying national-level likelihood of a given crop cultivated on organic soils based on GIS modelling using organic soils from FAO’s GeoNetwork tool (FAO, 2016) and crop area overlay from earthstat.org (Monfreda et al., 2008).

4. Synthetic Fertilizer Production

USDA NASS reports N, P and K synthetic fertilizer application rates by crop at a state level. These application rates represent the average application per *treated* acre per year for surveyed farms that report fertilizer treatments. However, the need to be multiplied by the

percent of planted acres that are treated (also a datapoint reported in USDA QuickStats) in order to arrive at an application rate averaged across all crop-specific planted acres within each state. These final application rates were used directly to estimate field-level emissions. To match these total N, P and K application rates to specific fertilizer types (e.g. Urea, NPK compounds, super triple phosphate etc.) for production modelling, 5-year average (2014-2018) data on regional fertilizer consumption rates from IFA statistics were used (IFA, 2021).

5. Manure Modelling

State-average manure application rates to cultivated cropland are not readily available. USDA ARMS has published survey data for the 2009-2011 period, but these are incomplete and insufficient for our purposes due to withheld and missing values.

State level manure ***nutrient*** availability has been estimated and reported by the US EPA (2023a,), which is based on animal populations and recoverability methodologies from Ruddy et al. 2006 (Table 12-5). In this method, manure nutrient produced by state is estimated using USDA statistics on the total number of animals.

Table 12-5. *Manure Nutrients (N and P) by State from EPA (2023a) for Relevant States.*

Estimated Animal Agriculture Nitrogen and Phosphorus from Manure				
Estimated Nitrogen (N) and Phosphorus (P) produced from animal manure in 2007 and 2017				
	Estimated animal manure in 2007 (1000 kg of N)	Estimated animal manure in 2017 (1000 kg of N)	Estimated animal manure in 2007 (1000 kg of P)	Estimated animal manure in 2017 (1000 kg of P)
Arkansas	179.024	177.07	56.005	55.61
Colorado	136.46	148.854	38.852	42.591
Idaho	115.094	134.107	27.493	32.768
Illinois	105.906	113.634	36.69	40.768
Indiana	103.411	113.665	35.432	38.951
Iowa	398.551	444.597	144.981	164.43
Kansas	293.838	296.306	84.863	86.7
Kentucky	144.122	141.038	43.414	43.296
Michigan	75.204	94.398	19.574	25.128
Minnesota	211.302	223.076	68.684	73.718
Mississippi	112.038	110.147	34.567	34.687
Missouri	261.45	274.52	84.045	90.007
Montana	131.048	139.67	41.155	44.343
Nebraska	314.619	339.465	96.219	104.094
New York	85.755	94.21	17.913	20.724
North Carolina	215.818	207.958	80.115	76.219
North Dakota	88.069	97.297	27.324	30.695
Ohio	108.025	125.12	32.516	39.11
Oklahoma	283.852	285.752	87.463	89.454
Oregon	74.777	72.489	21.237	20.716
Pennsylvania	125.555	138.231	32.946	37.876
South Carolina	47.205	46.239	15.054	14.565

South Dakota	189.425	220.371	59.013	68.847
Tennessee	124.787	111.367	38.148	34.213
Texas	699.431	687.364	206.361	202.317
Washington	63.537	69.943	16.069	17.816
Wisconsin	191.761	209.563	42.098	47.562

Using these estimates divided over cropland area from USDA NASS gives a value for average manure nutrient application rates on a land area basis. In reality, manure application is agronomically preferenced in combination with some crops over others. To reflect this preference, the state level manure availabilities from the EPA were scaled using national crop manure use estimates from the USDA ERS (Lim et al., 2023), supplemented with manure to sorghum from a previous USDA ARMS survey series, to more accurately reflect the manure use by crop type (see Table 4). This approach assumes that all manure is applied to only these crops. It's important to note that the manure use from this approach is accounting for "share of manured acres" rather than "share of manure amount", meaning that each manured acre is being treated the same regardless of the crop type. This is a limitation of the data but provides for improved specificity for the application of manure over the non-crop specific manure nutrient totals from Table 12-6.

Table 12-6. Share of Manured Acres by Crop.

Commodity receiving manure	Survey Year	Share of all manured acres (percent)
Corn	2016	58.3%
Hay and Pasture	2006	26.0%
Soybeans	2018	7.4%
Wheat	2017	3.6%
Cotton	2019	2.0%
Barley	2019	0.54%
Oats	2015	1.4%
Peanuts	2013	0.8%
Sorghum	2011	0.006%

Since the crop-specific manure use ratios in Table 12-6 are national averages, the resulting manure use needed to be scaled to fit the reality of each state (i.e. a state where corn represents 1% of cropland would not realistically apply 58% of manure to corn). In order to scale the crop-specific manure use ratios to match crop production within the state, state cropland profiles were developed that accounted for crop-specific planted area within a state divided by total planted area in the state which were then compared relative to a national average (i.e. compared to a national average, Iowa has 2.24 times as much cropland devoted to corn production). This step ensures that manure application rate estimates scale according to realistic production within each state, especially in states where corn production does not make up a significant proportion of the state's total crop production.

However, this also results in higher than possible manure use, according to the initial manure nutrient estimates from the EPA, in some states with relatively high proportions of cropland devoted to corn production. In order to fix this discrepancy, manure use was calculated for each of the crops listed in Table 4 and added together to estimate the state manure use total,

along with proportional use estimates for each crop within the state. The proportional manure use estimates were then reapplied to the EPA state manure nutrient totals in order to recalculate the crop-specific manure uses based on realistic manure totals while also accounting for crop-specific production ratios within each state. These nutrient values were used to calculate field emissions from nitrogen application.

In order to calculate the emissions due to transporting the manure, a manure amount had to be calculated based on the nutrients applied by the manure. Since the manure nutrients are not attributed to specific livestock species, we created a blend of manure types made based on the nutrient contents available from US manure totals by livestock type from (Kellogg et al., 2000).

6. Pesticide Production

The sum of active ingredient application rates per pesticide supergroup (insecticide, herbicide, fungicide) gathered from USDA NASS survey data for each crop were multiplied by the percent of planted acres treated to represent an average application rate across all planted acres. These application rates were linked to generic background datasets from Agri-footprint for the production of each pesticide super group.

7. Allocation to residue co-products

Since specific data for harvesting of residue co-product (i.e., stover, straw) is not available, we rely on the Agri-footprint default approach, which is to use half of the maximum sustainable removal rates from literature for cereals (Searle and Bitnere, 2017) and soybeans (Mcdonald, 2010).

Commodity prices came from a 3-year average of USDA NASS crop value summaries for 2022-2024, and dry matter content is based on harvest moisture content from USDA NASS. Price data for maize stover and sorghum straw came from Khanna et al., 2016. Prices for soybean straw and wheat straw came from Brhel et al., 2018 and Geist (2023), respectively. Dry matter contents of co-products were sourced from Feedipedia. Energy contents for both the main products and co-products were sourced from Feedipedia on a dry matter basis.

Table 12-7. Product Properties for Allocation.

Product	Price ($/kg)	DM (%)	Energy (MJ/kg DM)
Maize grain	0.20	84.5	18.7
Maize stover	0.02	92.8	18.2
Sorghum grain	0.20	87.0	18.8
Sorghum straw	0.02	93.0	18.1
Soybean	0.45	87.0	23.6
Soybean straw	0.05	89.1	19.0
Wheat	0.26	86.5	18.2
Wheat straw	0.06	91.0	18.5

Table 12-8. Allocation Factors for Products and Co-Products for the three Allocation Methods (Economic, Energy, and Mass).

Allocation Factors (%)			
Product	**Economic**	**Energy**	**Mass**
Maize grain	98.61	86.91	86.59
Maize stover	1.39	13.09	13.41

Sorghum grain	95.78	68.79	67.97
Sorghum straw	4.22	31.21	32.03
Soybean	97.73	85.30	82.36
Soybean straw	2.27	14.70	17.64
Wheat	91.23	69.19	69.54
Wheat straw	8.77	30.81	30.46

[1] Due to key datapoints being withheld by USDA in order to avoid disclosing data for individual operations.

[2] Enterprise budgets are economic budgets that typically reflect local practices and are based on aggregated data from growers. In our opinion, these sources better represent local conditions than (for example) modelled energy requirements since they reflect common local equipment/machinery and management practices, information that is not readily available for modelling purposes.

8. US-State level crop list

The list of crop/sub-region combination created for the US-state level dataset at cultivation crops stage are:

Crop Name	Subregion Code
Maize	US-CO, US-IA, US-IL, US-IN, US-KS, US-KY, US-MI, US-MN, US-MO, US-ND, US-NE, US-NY, US-OH, US-PA, US-SD, US-TX, US-WI
Sorghum	US-CO, US-KS, US-NE, US-SD, US-TX
Soybeans	US-AR, US-IA, US-IL, US-IN, US-KS, US-KY, US-MI, US-MN, US-MO, US-MS, US-NC, US-ND, US-NE, US-OH, US-SD, US-TN, US-WI
Wheat	US-ID, US-MN, US-MT, US-ND, US-SD, US-WA, US-CO, US-ID, US-IL, US-KS, US-KY, US-MI, US-MO, US-MT, US-NC, US-NE, US-OH, US-OK, US-OR, US-SD, US-TN, US-TX, US-WA

The sub-regions code per state are:

- **CO** → US-Colorado
- **IA** → US-Iowa
- **IL** → US-Illinois
- **IN** → US-Indiana
- **KS** → US-Kansas
- **KY** → US-Kentucky
- **MI** → US-Michigan
- **MN** → US-Minnesota
- **MO** → US-Missouri
- **ND** → US-North Dakota
- **NE** → US-Nebraska
- **NY** → US-New York
- **OH** → US-Ohio
- **PA** → US-Pennsylvania
- **SD** → US-South Dakota
- **TX** → US-Texas
- **WI** → US-Wisconsin
- **AR** → US-Arkansas

Appendix X AusLCI crop list

The list of crop/sub-region combination created for the Australian LCI level dataset at cultivation crops stage are:

Crop Name	Subregion Code
Barley grain	AU-NSW, AU-QLD, AU-SA, AU-TAS, AU-VIC, AU-WA
Field bean	AU-SA
Peas, dry	AU-NSW, AU-SA, AU-VIC, AU-WA
Beans, dry	AU-NSW, AU-QLD
Broad beans	AU-NSW, AU-QLD, AU-SA, AU-VIC, AU-WA
Chickpea	AU-NSW, AU-QLD, AU-SA, AU-VIC, AU-WA
Lentils	AU-NSW, AU-QLD, AU-SA, AU-VIC, AU-WA
Lupins	AU-NSW, AU-QLD, AU-SA, AU-VIC, AU-WA
Maize	AU-NSW, AU-QLD, AU-SA, AU-VIC, AU-WA
Oat grain	AU-NSW, AU-QLD, AU-SA, AU-TAS, AU-VIC, AU-WA
Rapeseed	AU-NSW, AU-SA, AU-TAS, AU-VIC, AU-WA
Sorghum grain	AU-NSW, AU-QLD, AU-VIC
Sunflower seed	AU-NSW, AU-QLD, AU-VIC
Wheat grain	AU-NSW, AU-QLD, AU-SA, AU-TAS, AU-VIC, AU-WA

The sub-regions code per state are:

- **NSW** → New South Wales
- **QLD** → Queensland
- **SA** → South Australia
- **TAS** → Tasmania
- **VIC** → Victoria
- **WA** → Western Australia

Appendix XI List of products with a coverage < 50%.

As a rule, we decided to create market mixes and production mixes of products when the coverage was equal or bigger than 50 %. In Table 12-9 and Table 12-10 we share the Market mixes where the products were not allowed to reach this 50 % of coverage:

Table 12-9: Products with a Market Mix coverage lower than 50%.

Product Name	M. Mix Covered (%)
Crude palm kernel oil, market mix, at regional storage {NL} Economic	43.81%
Soybean hull (solvent), market mix, at regional storage {NL} Economic	48.85%
Soybean meal (solvent), market mix, at regional storage {RNA} Economic	48.26%
Sugar beet pulp dried, market mix, at regional storage {RER} Economic	30.97%
Coconuts, dehusked, market mix, at regional storage {NL} Economic	10.35%
Lucerne, market mix, at regional storage {RER} Economic	37.18%
Cereals, nes, market mix, at regional storage {NL} Economic	9.61%
Cereals, nes, market mix, at regional storage {RER} Economic	1.36%
Lucerne, market mix, at regional storage {NL} Economic	12.57%
Coconuts, dehusked, market mix, at regional storage {RER} Economic	9.41%

Table 12-10: Products with a Production Mix coverage lower than 50%.

Product Name	Production Mix Covered (%)
Berries nes, production mix, at orchard {RER} Economic	5.01%
Cereals, nes, production mix, at farm {GLO} Economic	4.96%
Cereals, nes, production mix, at farm {RER} Economic	6.90%
Cherries, production mix, at orchard {RER} Economic	15.49%
Chillies and peppers, green, production mix, at farm {RER} Economic	37.45%
Cow peas, dry, production mix, at farm {GLO} Economic	43.95%
Cranberries, production mix, at orchard {RER} Economic	44.49%
Hempseed, dried, production mix, at storage {GLO} Economic	8.67%
Melonseed, production mix, at farm {GLO} Economic	2.91%
Oilseeds nes, production mix, at farm {GLO} Economic	11.69%
Oilseeds nes, production mix, at farm {RER} Economic	24.65%
Onions, shallots, green, production mix, at farm {GLO} Economic	41.95%
Onions, shallots, green, production mix, at farm {RER} Economic	22.57%
Strawberries, production mix, at farm {RER} Economic	31.55%
String beans, production mix, at farm {GLO} Economic	3.04%
Sugar crops, nes, production mix, at farm {GLO} Economic	46.79%
Tomatoes, production mix, at farm {RER} Economic	41.06%
Vetches straw, production mix, at farm {GLO} Economic	5.29%
Vetches straw, production mix, at farm {RER} Economic	1.68%
Vetches, dried, production mix, at storage {GLO} Economic	5.29%
Vetches, dried, production mix, at storage {RER} Economic	1.68%
Lucerne, production mix, at farm {GLO} Economic	6.51%

Appendix XII Critical Review

An independent critical review of the Agri-footprint 8 database was conducted by the Life Cycle Assessment (LCA) Research Group at Agroscope in Zurich, Switzerland. The primary aim of this evaluation was to verify whether the methodology, data, and reporting of Agri-footprint 8 fulfil the international standards set by ISO 14040 and ISO 14044 for generic life cycle inventory databases. Agroscope assessed the database's methodological documentation, database-wide statistical balances, and 14 detailed representative datasets spanning diverse geographic locations, product groups, and supply chain stages.

Agroscope concluded that Agri-footprint 8 is compliant with ISO 14040 and ISO 14044 guidelines, with its methodology and limitations transparently documented. Providing over 10,000 datasets covering 1,400 products across 142 countries, the database ensures comparability between datasets and alignment with global figures by relying mainly on international statistics, such as FAOSTAT, and standard emission modelling guidelines from IPCC and EEA/EMEP. Consequently, the review confirms that AFP8 is suitable for use as a secondary background database in life cycle assessment studies across the agri-food sector.

The review statement, and the authors response have been included below.

Note on digital signatures: the review statement included in the following pages was officially signed using qualified electronic signatures (QES). Because appending the report into this document alters document, cryptographic validation cannot be performed on the merged version. The original, unmerged document is available upon request by contacting info@blonksustainability.nl and can be validated at validator.ch.

Authors response

Mérieux NutriSciences | Blonk welcomes the independent critical review of Agri-footprint 8, conducted by the LCA Research Group at Agroscope under the leadership of senior researcher Dr. Thomas Nemecek.

Agri-footprint is developed to provide the LCA and agri-food communities with transparent and methodologically consistent environmental data. Independent critical review plays a crucial role in ensuring the database continues to meet requirements and practical needs of its users. The Agroscope review provides an external assessment of these aspects.

The review process resulted in improved documentation transparency, metadata clarity and helped resolve technical issues. While Agri-footprint 8 represents a major step forward, the review also highlights methodological choices and data limitations that users should consider when applying the database in LCA studies. We highlight two considerations:

- Data quality indicators: In this version, uncertainty distributions are defined around five-year crop yield variations only. Because parameter-level distributions are not yet uniform across all secondary inputs, running database-wide Monte Carlo simulations is currently not recommended.
- Data quality ratings (DQR): A DQR implementation aligned with the latest PEF DQR specification has been added to our development roadmap and will likely be included in the next major update of Agri-footprint.

We thank the Agroscope review team for their thorough assessment and constructive contributions. The review provides valuable input for further strengthening Agri-footprint and guiding its future development. We remain committed to developing Agri-footprint as a transparent and methodologically consistent source of environmental data for agricultural production and food systems worldwide.

The Agri-footprint team

Mérieux NutriSciences | Blonk, Rotterdam, October 2026

Critical review of Agri-footprint V8 by Agroscope

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The reviewers declare no conflicts of interest related to this review.

2. Aim and scope of the review

2.1 Aim and scope

The aim of this review was to verify, whether the Agri-footprint database version 8 (AFP8) meets the requirements for methodology, data and reporting defined by the ISO 14040/44 standards. The criteria of the ISO standards were considered to the extent they are applicable to a generic LCI database. We have reviewed the documentation of the database, selected datasets and the calculated environmental impacts, as described in Section 3.

2.2 Out of scope

The following aspects and tasks were out of scope for this review:

- Detailed check of each dataset in the database.
- Check of all inventory flows by independent recalculation.
- Check of the compliance with the guidelines for Forest, Land and Agriculture (FLAG) of the Science Based Targets Initiative.
- Check of the compliance with guidelines for the Product Environmental Footprint (PEF) of the EU, including specific category rules (PEF-CR).
- Alignment of the AFP8 elementary flows with LCIA methods.
- Systematic comparisons of AFP8 with other databases, the literature or previous AFP versions.
- Datasets for Australia in AFP8 were excluded from the review, as they were not finalised at the time of the review.
- The different calculation engines, used for the calculation of the inventories were not verified. Only the documentation of the emission calculations was reviewed, as far as relevant for this review.

- The mass and energy allocated versions of AFP8 were excluded from the review; only the version with economic allocation was reviewed. Yet, the values used for the calculations for all three versions in the methodology reports were checked.
- Part 3 of the documentation was not reviewed.

3. Review procedure

3.1 Procedure and timeline

9 June 2026: Kick-off
24 June 2026 Progress meeting
16 July 2026 Progress meeting
19 August 2026 Progress meeting
23 September 2026 Finalisation of the review report.

Review comments were provided by Agroscope to "Mérieux NutriSciences | Blonk" (hereafter called Blonk MXNS) in two rounds. Collaborators of Blonk MXNS have responded to the comments. Comments that could be satisfactorily resolved during the review project are not mentioned in this report.
The review refers to the documents, datasets and environmental indicators made available to the reviewers at the time of the review (see Annex 6.2). Possible later changes of the documentation, data values, meta-data or plans for future developments were not considered.

In addition, optional suggestions for future developments of the Agri-footprint database were provided by the reviewers, which were not part of this review.

3.2 Review criteria

The criteria for this review were derived from the ISO 14040/44 standards and are listed in Annex 6.1.

3.3 Selection of datasets for detailed review

A representative sample of inventory datasets was selected for the review based on three criteria:

1. Geographical diversity: ensuring that reviewed datasets covered different countries and world regions,
2. Product diversity: including a variety of food groups, such as cereals, fruits, vegetables, meat and fish,
3. Life cycle stage diversity: covering all stages in the database, i.e., primary production, processing, market mix, production mix and storage.

Five datasets were proposed by Blonk MXNS, and nine selected by Agroscope. The list of the 14 reviewed datasets, together with the rationale for their selection, is provided in the Appendix 6.3.

3.4 Statistical evaluation of environmental impact indicators

Agroscope conducted three systematic checks across the entire inventory database:

1. Land Transformation Balance: checked whether the sum of "transformation, to (…)" values always equaled the "transformation, from (…)" values in the biosphere flows. A tolerance of 10^{-6} m² was applied to allow for rounding.

2. Balance Land Occupation & Infrastructure: checked whether the sum of total land occupation always equaled the area of "Basic infrastructure".
3. GWP disaggregated impact results: Agroscope checked whether the sub-categories of the GWP impact category (i.e. "excl. LUC and peat oxidation", "only LUC", "only peat oxidation") add up to the reported GWP incl. LUC and peat oxidation.

4. Results of the review

4.1 Types of review comments

Three types of review comments were made:

1. Major comments: relevant criteria of the ISO standards which are not or not fully met.
2. Minor comments: minor inconsistencies or errors, unclear parts of the reports, etc.
3. Suggestions: proposals on how the database could be further improved in the future, such as using new/better data sources, models, emission factors, new modelling approaches. These suggestions are not reported in this review statement.

4.2 General assessment

AFP8 is a comprehensive database for the agri-food sector, providing more than 10,000 datasets for a total of 1400 products and 142 countries. It comes with extensive documentation, consisting of meta-data contained in each of the datasets and several reports, available to the users. The documentation is generally detailed, comprehensive and transparent.
Input use modelling mainly relies on international statistics, where available, which ensures the consistence with global figures and comparability between countries. Emissions are modelled in a systematic way, which safeguards comparability between datasets. For crop production, greenhouse gases and some related emissions are largely modelled using Tier 1 methodology from IPCC, which ensures the consistency with IPCC guidelines for national GHG inventories. For emissions from crop production, relatively simple Tier 1 emission factors and models are used, e.g. for P emissions or nitrate leaching. This causes to some extent a lack of specificity; more detailed models and data are available at national and regional levels, which are not taken into account. Modelling for animal systems is more detailed and specific than modelling of crop production and mostly follows relevant guidelines from IPCC and EEA/EMEP.
The target users and intended applications are specified. Main limitations are mentioned in various chapters of the methodological reports, which helps users to evaluate the usability of the datasets for their specific purposes.
Data quality indicators are missing. AFP8 only provides uncertainty indicators for crop yields.

4.3 Detailed assessment

- Capital goods: AFP8 includes basic infrastructure of agricultural land, tractors and silos. Other capital goods (such as animal housings, farm equipment, etc.) are not considered, so that the impacts may be underestimated.
- Fertiliser modelling relies on recent georeferenced maps for fertiliser doses and harvested areas of crops. The calculated amounts of fertilisers are crop and country specific.
- Pesticides: the amounts of pesticides applied per crop and country are among the most relevant data gaps in LCI databases. AFP8 uses FAOSTAT data for the quantities of pesticide used per group and per country. Data from France, the Netherlands and the United States are used to disaggregate the pesticide quantities per crop group and to define the active ingredients applied within each crop group for the countries considered in AFP8. This procedure provides robust estimates, which has some limitations in terms of specificity to crop-country combinations (see below).

- Water use: the modelling has been updated and extended; now it also includes capillary rise, which we consider as an important innovation.
- Transports: AFP8 includes a detailed modelling of transport modes. Transports are considered in a systematic way per life cycle stage.
- Market and production mixes: the market and production mixes are updated in AFP8. A detailed description and visual representation of how these are modelled is provided in the report, along with the approach to dealing with missing data, and the transportation requirements.
- Emissions from the cultivation of drained peat soils are now included in AFP8. The estimates are based on the National Inventory Reports (NIR) for GHG. The average estimates were corrected by using other sources to derive crop-country specific emission values. The method ensures consistency with the NIRs.
- US LCI: the emissions of the original datasets from the American Feed Industry Association (AFIA) were recalculated, using the AFP8 methodology, which ensures consistency with other datasets in the database.
- Allocation procedures: AFP8 provides three allocated versions (economic, mass and gross energy). The allocation is applied systematically to all datasets in the database, so that consistency is ensured across all datasets.

4.4 Statistical evaluation results

1. Land Transformation Balance: five inventories exceeded the defined tolerance.
2. Balance Land Occupation & Infrastructure: the sum of total land occupation always equaled the area of "Basic infrastructure" for all food inventories.
3. GWP disaggregated impact results: the sub-categories of the GWP impact category (i.e. "excl. LUC and peat oxidation", "only LUC", "only peat oxidation") add up to the reported GWP incl. LUC and peat oxidation for all datasets.

4.5 Notes for users of the database

- Capital goods: apart from basic infrastructure of agricultural land, tractors and silos, no other infrastructure is included.
- Pesticide active ingredients have a limited specificity to crops; therefore, datasets may include active ingredients that are not applied or not registered for that crop in the respective country.
- Seed: some seed quantities were found to be unrealistic. Generally, seed impacts make up a few percent of the impacts of crop cultivation.
- Cooled and frozen transports are not considered. In cases, where goods need to be cooled or frozen during transport, the related impacts could be underestimated.
- Euro emission standards for transports (e.g., Euro 3, Euro 4, Euro 5) are not differentiated across datasets locations. This may lead to over- or underestimation of impacts, as older standards (e.g., Euro 3) have higher emissions and remain prevalent in developing regions (e.g., Africa, Asia, Latin America), for which AFP8 includes inventories.
- Since data quality indicators are generally missing from the database, users should not perform Monte Carlo analyses with AFP8 in its current state, since the analysis will not provide meaningful results.

5. Conclusion

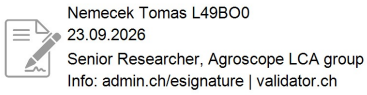
APF8 is a comprehensive database for the agri-food sector, with significant updates using recent sources. Dataset generation follows systematic procedures, to a large extent based on global statistics, ensuring comparability across datasets and consistency with global statistics.

Systematic allocation procedures safeguard the allocation rules throughout the database. AFP8 is compliant with the ISO 14040 and 14044 guidelines and the limitations are transparently documented.
The database is suitable for the use as background database in LCA studies for the agri-food sector. Users looking for very specific information (e.g., a single ingredient dominating the impact) are advised to thoroughly check the underlying data and the suitability for their specific goal and scope and – where needed – adapt or complement the datasets with primary data.

Agroscope, Life Cycle Assessment Research Group

Zurich, September 2026

Dr. Thomas Nemecek



Dr. Mara Petruzzelli



Clara Payró



Martin Stüssi



6. Annexes

6.1 Detailed listing of review criteria

6.1.1 Methodology reports

General:

- Clarity, completeness and transparency of the documentation

Goal and scope:

- Suitability to the intended applications
- Target audiences
- Definition of functional units/reference flows
- System boundaries
- Omissions of life cycle or processes clearly documented
- Description of cut-off criteria and assumptions

Life cycle inventory:

- Data collection procedures
- Qualitative and quantitative description of unit processes
- Sources of published literature
- Calculation procedures
- Data quality analysis
- Treatment of missing data
- Proxy definition adequate and clearly documented
- Documentation and justification of allocation procedures
- Uniform application of allocation procedures

6.1.2 Selected datasets

- Naming of the dataset
- Meta-data, general description: does it contain the information relevant for the users
- Meta-data: comments to individual flows
- Consistency between the dataset contents and the methodology reports
- Plausibility of the numerical values
- Uncertainty information

6.2 Documents received

The data of delivery of the documents is given in [brackets].

Main reports:

- Agri-footprint 8 - Methodology Report - Part 1 Methodology and Basic Principles MxNS branding.docx [9 June 2026; 19 August 2026]
- Agri-footprint 8 - Methodology Report - Part 2 - Description of Data MxNS Branding.docx [9 June 2026; 19 August 2026]

Supporting documents:

- APS Beef Documentation.pdf [9 June 2026]
- Memo on Blonk-selected processes for review.docx [9 June 2026]
- Memo on the blonk-made adaptations to the ReCiPe method.docx [9 June 2026]
- Memo-Beef datasets review.docx [9 June 2026]
- 20260422 Crop Life Cycle Engine.pdf [25 June 2026]
- APS Beef Documentation.pdf [25 June 2026]
- APS Dairy Documentation - July 2024.pdf [25 June 2026]

- APS pigs Documentation - System definition and methodology 20250825.pdf [25 June 2026]
- AFIA Data-in Project Documentation for GFLI Review (Updated_1-23-2026).docx [2 July 2026]
- WRI Phase 1 review of LUC tool_211113.xlsx [2 July 2026]
- animal-systems-comment-mapping.xlsx [8 July 2026]
- Selective updates of parts of the documentation [August-September 2026]

Data files and database access:

- AFP8_SP_10_4.csv [9 June 2026]
- AFP8_impacts.xlsx [9 June 2026]
- Blonk method 4.2.0 - based on ReCiPe 1.13.CSV [9 June 2026]
- AFP8_adaptation_to_SP10_3.XLSX [9 June 2026]
- AFP8_SP_10_4_adapted.csv [9 June 2026]
- Blonk method 4.2.0 - based on ReCiPe 1.13_adapted.CSV [9 June 2026]
- AFP8_impacts.xlsx [19 August 2026]
- Access to the internal database [19 August 2026]

6.3 Datasets reviewed in detail

Suggested by	Dataset Name	Location	Stage	Reason for selection
Agroscope	Soybeans, at farm	BR	at farm	Soybean in Brazil is a main crop. This dataset is reviewed in parallel with soybean meal
Agroscope	Bananas, at orchard	ET	at orchard	Represents a location different from other production countries for a widely modelled product within the database (n=58), and provides a dataset from an African country
Agroscope	Milk raw, at farm	FR	at farm	A dairy dataset that is reviewed in parallel to cheese production.
Agroscope	Watermelons, production mix, at farm	GLO	at farm	A fruit inventory, representing a widely modelled inventory within AFP8 and that is similar to some vegetable crops such as cauliflower. This dataset is also a production mix, which is a new concept added to the database.
Agroscope	Maize, dried, market mix, at regional storage	PL	at regional storage	A market mix of a widely modelled product food product within AFP8.
Agroscope	Wheat grain, winter, at farm	US-ID	at farm	A cereal product in the US, as the US are modelled differently from other countries.
Agroscope	Cod edible part, at processing	NO	at processing	A fish inventory and a processing inventory
Agroscope	Cheese, from cheese production, at processing	FR	at processing	A dairy product, including milk production, and a post-harvest level process, to cover all modelled life cycle stages
Agroscope	Ammonia, as 100% NH3 (NPK 82-0-0), at plant	FSU	at plant	A high-impact process of high complexity
Blonk MXNS	Rice, at paddy	CN	at paddy	An arable crop that reflects most of the methodological improvements developed for this AFP version. Specifically for rice cultivation, methane emission modelling from paddy fields was updated
Blonk MXNS	Apples, at orchard	NL	at orchard	This is a new process, part of the fruits and vegetable scope extension of the AFP8 database
Blonk MXNS	Pig fattening, at farm	DK	at farm	All animal systems were remodelled for AFP8. For pigs, the Danish system is representative of how all pig systems in the database were modelled

Suggested by	Dataset Name	Location	Stage	Reason for selection
Blonk MXNS	Beef cow finished, suckler extensive, at farm	FR	at farm	The animal system scope was expanded to include beef systems. This specific dataset is representative of a cow-calf closed system, including both breeding and growing stages. It incorporates both single ingredients and compound feed ingredients. This system is further connected to fattening systems, representing the selling of beef calves to be fattened and finished in Italy.
Blonk MXNS	Soybean meal (solvent), at processing	BR	at processing	One of the most important datasets in the database with respect to feed production