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World Food LCA Database

Methodological Guidelines for the Life Cycle Inventory of Agricultural Products

WORLD FOOD LCA DATABASE

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Disclaimer

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Acronyms and abbreviations

AGB	Aboveground biomass
ADEME	Agence de l'environnement et de la maîtrise de l'énergie
BGB	Belowground biomass
BMR	Ratio defined as the kg beef sold per kg milk sold annually
BRIC	Brazil, Russia, India and China
BSI	British Standards Institution
C	Carbon
Cd	Cadmium
CFT	Cool Farm Tool
CH_4	Methane
CO_2	Carbon dioxide
Cr	Chromium
Cu	Copper
dLUC	Direct land use change
DOM	Dead organic matter
EDA	European Dairy Association
EEA	European Environment Agency
EF	Emission factor
EU-JRC	European Commission - Joint Research Centre
FAO	Food and Agriculture Organization of the United Nations
FEFAC	European Feed Manufacturers Federation
FPCM	Fat and protein corrected milk
ICID	International Commission on Irrigation and Drainage
IDF	International Dairy Federation
IEA	International Energy Agency
ILCD	International Reference Life Cycle Data System
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
FOAG	Swiss Federal Office for Agriculture
FOEN	Swiss Federal Office for the Environment
GRUDAF	Grundlagen für die Düngung im Acker- und Futterbau
HAFL	Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften
Hg	Mercury
K	Potassium
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle inventory assessment
LEAP	Livestock Environmental Assessment and Performance
LPG	Liquefied petroleum gas
LUC	Land use change
MCF	Methane conversion factor
N	Nitrogen
N_2O	Dinitrogen monoxide or nitrous oxide
NH_3	Ammonia
NO	Nitrogen monoxide
NO_3^-	Nitrate
NOx	Nitrogen oxides
Ni	Nickel
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
Pb	Lead
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules

PO_4^{3-}	Phosphate
SALCA	Swiss Agricultural Life Cycle Assessment
sLUC	Statistical land use change
SOC	Soil organic carbon
TAN	Total ammoniacal N (kilograms N)
USDA	United States Department of Agriculture
UofA	University of Arkansas
WFLDB	World Food LCA Database
WWTP	Waste water treatment plant
Zn	Zinc

1 Introduction

1.1 Background and History

Agricultural production and food processing contribute significantly to environmental impacts on global warming, eutrophication and acidification (Pardo and Zufia 2012; Ruviaro et al. 2012; Saarinen et al. 2012). In the last decade, life cycle assessment (LCA) is increasingly used for the quantification of these impacts and to meet the demand for optimization of food production (Notarnicola et al. 2012). For an environmental assessment of food products, the data demand comprises not only the agricultural primary production but also food processing, packaging, transport and waste management. Furthermore, a huge variability of agricultural practices exists within a country and to an even larger extent on a global scale.

Due to complexity and variability of agricultural life cycle inventories, it is important to ensure that agricultural datasets are:

- Transparent and well documented
- Complete: all relevant inventory flows are accounted for, which leads to a complete overview of the impacts of food products and avoids misled interpretations and conclusions
- Consistent among each other, aligning approaches and assumptions
- Regularly updated
- Regionalized when relevant: country-specific data are available or at least the region under study is represented

The World Food LCA Database (WFLDB) project was launched in 2012 by Quantis and Agroscope to address these needs. After a first release in 2013 (version 1.0), the Guidelines have been regularly updated and completed until the present Guidelines version 3.5 (full history is presented in Tab. 1). It describes the modelling of the WFLDB 3.5 datasets to be released end of 2019.

Tab. 1: History of the WFLDB and its Methodological Guidelines

Year	Phase	Guidelines version	Database version	Ecoinvent background version
2013	I	1.0	N/A	2.2
2014	I	2.0 (*)	WFLDB 1.0	2.2
2015	I	3.0	WFLDB 3.1	2.2
2017-18	II	3.1 – 3.4	WFLDB 3.2 – 3.4	3.3
2019	II	3.5 (*)	WFLDB 3.5 (*)	3.5

(*) public release (as opposed to internal release, reserved to WFLDB partners)

1.2 Objectives

The main aim of the WFLDB is to create a database that represents agricultural primary products and processed food products. The geographical focus is global, i.e. products that are dealt on the global market are represented. The WFLDB can assist companies and environmental authorities in processes like eco-design of food products, Environmental Product Declarations (EPD) and further Product environmental footprint (PEF), and can also be used for academic research. For this purpose, a new set of food inventory data is being developed from existing LCA studies on food products (project partners' previous LCAs, Agroscope and Quantis existing databases), literature reviews, statistical databases of governments and international organizations (such as the Food and Agriculture Organization of the United Nations), environmental reports from private companies, technical reports on food and agriculture, information on production processes provided by the project partners as well as primary data.

A list of products[1] and processes was defined with the objective to represent at least 50% of the global market in mass for selected products and processes. The list has been developed according to the following procedure:

- An individual list of priorities regarding products and processes was developed from each WFLDB partner based on the "UN Classification of Individual Consumption According to Purpose (COICOP)" classification system
- FAO statistics (http://faostat3.fao.org/home/index.html; year: date is specified in the dataset documentation) was used to identify the most important net-export countries and define the countries that are considered in WFLDB
- An average priority score for each product and process was calculated
- The final list was defined according to priorities and available budget
- Some products or countries were deliberately not selected because LCI data of sufficient quality was already available in other databases

A few home cooking datasets are also included in the database, even if they appear beyond the scope of food products. The intention is to enable a few comparisons taking into account this key step when considering food "from field to fork". However, beside exceptions, packaging, distribution, refrigeration and washing are not included.

This document describes the methodological approaches and the decisions that have been taken to model the WFLDB datasets within the project.

[1] The list is available with the documentation report (Bengoa et al. 2020).

2 General principles

This document describes the scientific modelling principles, methods and approaches that are applied for the WFLDB datasets. This report aims to present a consistent and transparent methodology that is exhaustive enough to be applicable on a global scale.

2.1 Database structure

The WFLDB aims to be representative of the global market. Therefore, whenever it was possible:

- For each product, at least 50% of cumulated global exports are represented by the countries considered
- In each represented country, a representative production system is modelled (if not possible, an adapted version of the known system is built based on available local data)
- Representative production system on a global level for some manufacturing/conversion processes

The modelling guidelines are based on existing scientific modelling guidelines and are compliant with the following standards:

- Ecoinvent data quality guideline (ecoinvent report No. 1(v3): overview and methodology – data quality guideline for the ecoinvent database version 3) (Weidema *et al.* 2013)
- ISO 14040 and 14044 (ISO 2006a; 2006b)
- ILCD (entry level requirements) (EU-JRC 2012)
- PEFCR Guidance 6.3 (EC-JRC 2017)

All datasets in WFLDB are modelled on a unit process level and all methodological choices that have been taken are described in this document and in the dataset documentation to reach a high transparency. Ecoinvent is used as background database. A documentation report (Bengoa et al. 2020) gives more details about the data and assumptions used for modelling. It also comes with an excel file listing all datasets created in the WFLDB project.

2.2 Naming convention

The ecoinvent naming convention is applied, as documented in the ecoinvent report No. 1 (v3) "Overview and methodology: Data quality guideline for the ecoinvent database version 3", chapter 9 (Weidema *et al.* 2013). Activities (e.g. coffee spray drying) are differentiated from intermediary exchanges – or products – (e.g. coffee, spray dried).

The name of agricultural products datasets explicitly includes the following:

- Product name (incl. variety, when relevant)
- Product grade (when relevant)
- Production scheme (conventional, organic, intensive, extensive, etc.)
- Production mode (open field, greenhouse heated, greenhouse non-heated, etc.)
- Country of production

Naming of datasets might be adapted if or when the WFLDB is provided as part of another LCI database, LCI data platform or LCA software. Typically, when datasets are published through the

European Life Cycle Data Network, they shall follow the compliance rules and entry-level requirements (EU-JRC 2012) and must therefore be renamed according to ILCD conventions (EU-JRC 2010b).

2.3 Functional unit and reference flows

In life cycle assessment, the functional unit is the reference for evaluating products, services and activities on a common basis. The reference flow is the amount of product or activity required to fulfil the functional unit. Typically, life cycle inventory (LCI) data rely on a chosen reference flow.

Agricultural datasets (i.e. crop products) are based on a mass reference of one kilogram (1 kg) of output fresh product. The reference flow can therefore be defined as:

1 kg output fresh product, unpackaged, at farm exit gate

The water content of the product is specified in the dataset description.

For live animal production, the reference flow is defined as:

1 kg animal, live weight, at farm exit gate

1 kg fresh chicken eggs, unpackaged, at farm exit gate

1 kg fat and protein corrected milk (FPCM), unpackaged, at farm exit gate

with

1 kg FPCM = 1 kg milk * (0.1226 * %fat + 0.0776 * %true protein + 0.2534) (IDF, 2015)

For transformed food items:

1 kg animal product, unpackaged, at slaughterhouse exit gate (fresh meat)

with different co-products (food grade co-products, hides and skin, etc.) allocated to the total dead weight of the animal. See section 2.6.4 for more details.

1 kg product, unpackaged, at plant exit gate

For food transformation activities:

Activity datasets, or transformation activities (e.g. slaughtering, drying, home cooking, etc.), can be based on a mass reference of one kilogram (1 kg) of input product, a unitary reference (1 unit), or a time reference (1 min). The reference flow can therefore be defined as:

Transforming 1 kg (or 1 unit) of input product
Cooking 1 kg (or 1 min) of food product

Sub-datasets developed for the WFLDB can be based on other reference flows that nevertheless remain consistent with the usual practices in the ecoinvent database (e.g. 1 kWh electricity, 1 MJ heat, 1 m^3 irrigating).

2.4 System boundaries

The following sections describe the system boundaries defined in WFLDB in three categories: crop production, animal production and food transformation. For both crop and animal production, a cradle to gate approach is chosen while for food transformation[2] a gate-to gate approach is applied.

Home cooking is included, even if it appears beyond the scope of food supply. The intention is to enable a few comparisons taking into account this key step when considering food "from field to fork".

2.4.1 Crop production

System boundaries for crop production systems are illustrated in Figure 1. By default, conventional seeds are used. On a case-by-case basis, treated seeds are modelled (e.g., coating). Irrigation water energy and infrastructure, as well as the water extraction from nature are included. Transport of material inputs and on-farm transport are included. Drying of cereals before storage is included whether it takes place at the farm or elsewhere. Waste and wastewater treatment are included.

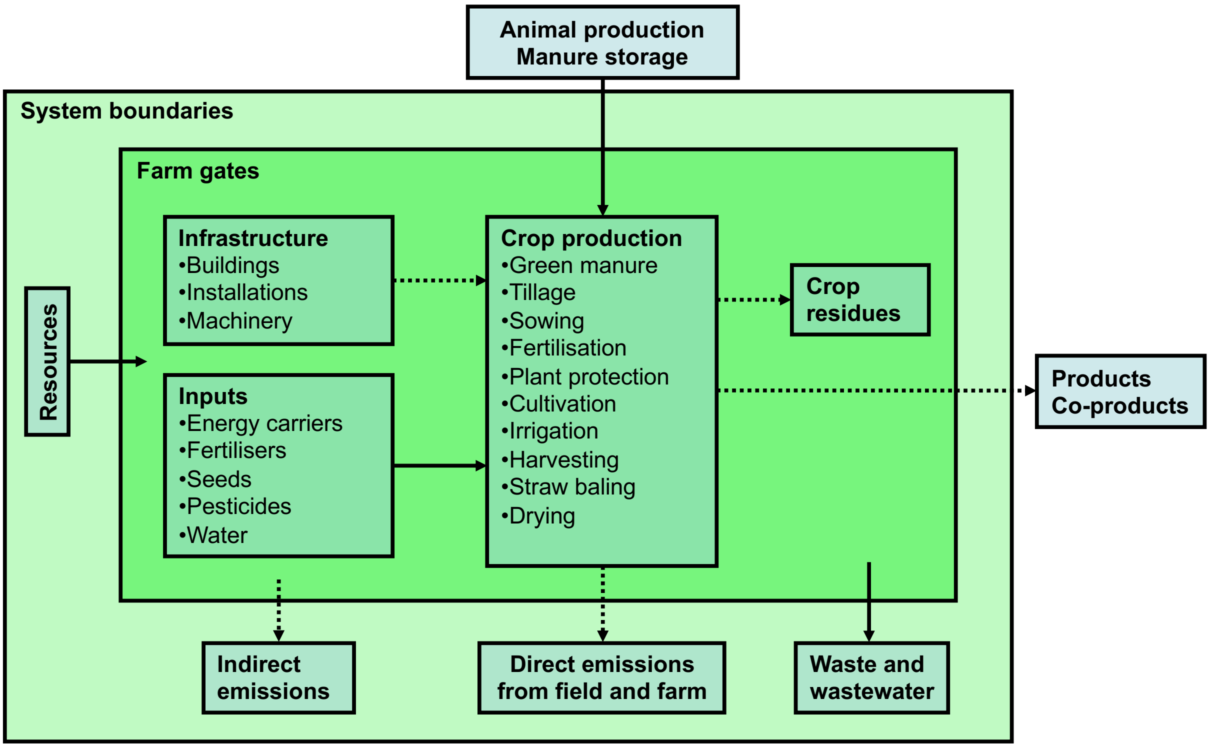

Figure 1: System boundaries for crop production systems. Dotted arrows denote absence of transportation (or neglected)

Excluded processes are:

- Animal traction
- Post-harvest processes, except drying and post-harvest pest treatment when rendered mandatory for proper storage of crop products and specific post-harvest activities taking place at the farm (e.g. depulping)
- Production and storage of animal manure

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[2] The term "food transformation" is used since it covers both industrial food processing and home cooking.

- Packaging of output products, unless specifically mentioned
- Labour, commuting and travels of seasonal workers
- Administrative work
- Processes that can reasonably be assumed to contribute to less than 1% of the environmental impact (cut-off criterion, applied only when no data are available).

2.4.2 Animal production

System boundaries for animal production systems are illustrated in Figure 2. All relevant input processes and resources are accounted for. Feed production and processing is included whether it takes place at the farm or externally (hence the dashed line).

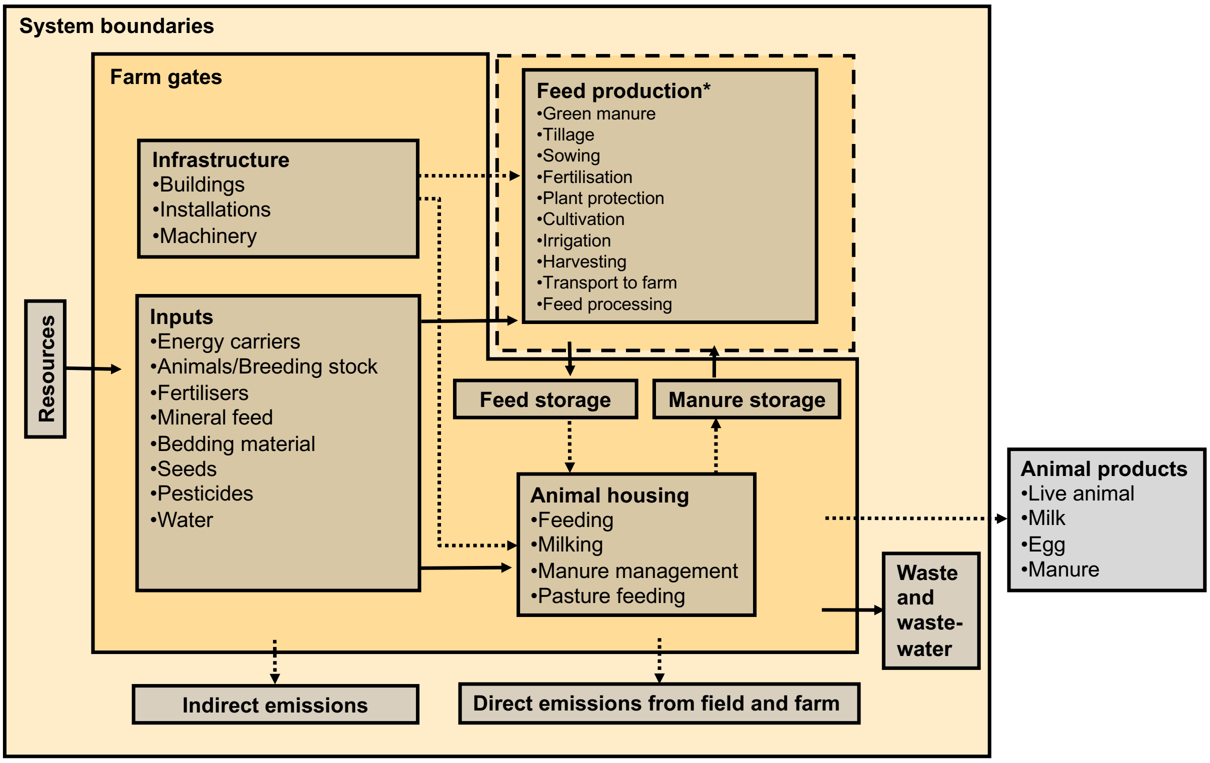

Figure 2: System boundaries for animal production systems. Dotted arrows denote absence of transportation (or neglected)

Excluded processes are:

- Pharmaceuticals
- Packaging of output products, unless specifically mentioned
- Labour and commuting
- Administrative work
- Processes that can reasonably be assumed to contribute to less than 1% of the environmental impact (cut-off criterion, applied only when no data are available).

2.4.3 Food transformation

System boundaries for food transformation systems are illustrated in Figure 3 and Figure 4.

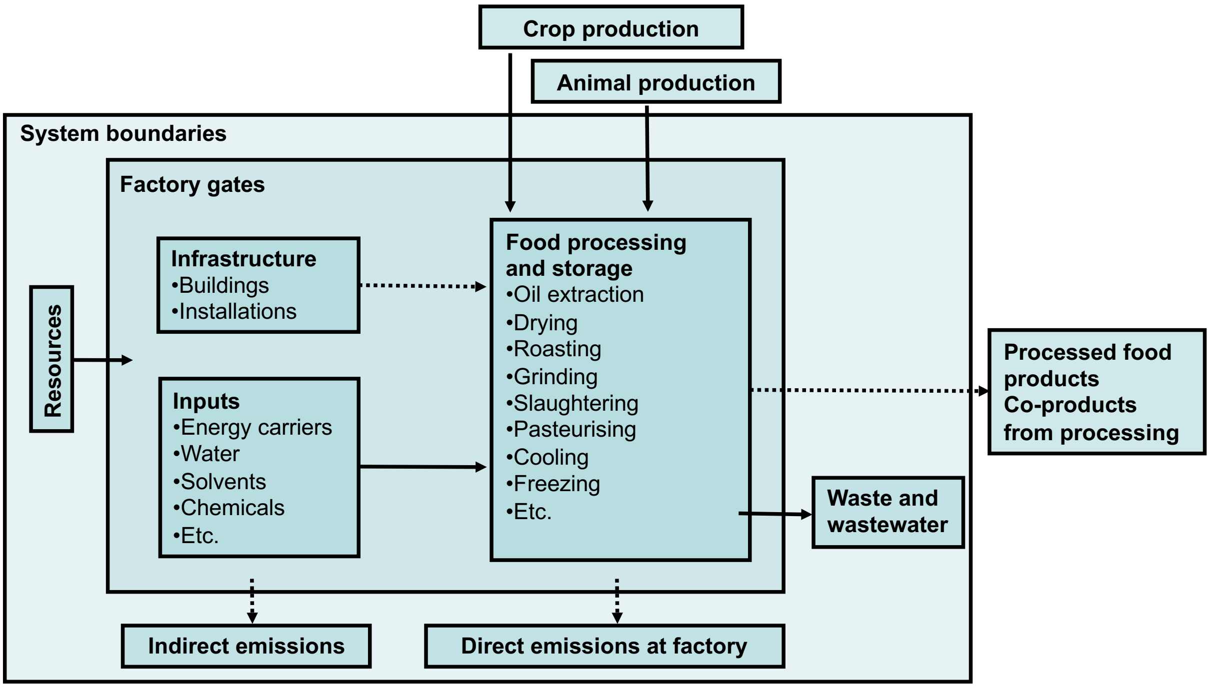

Figure 3: System boundaries for food processing systems. Dotted arrows denote absence of transportation (or neglected)

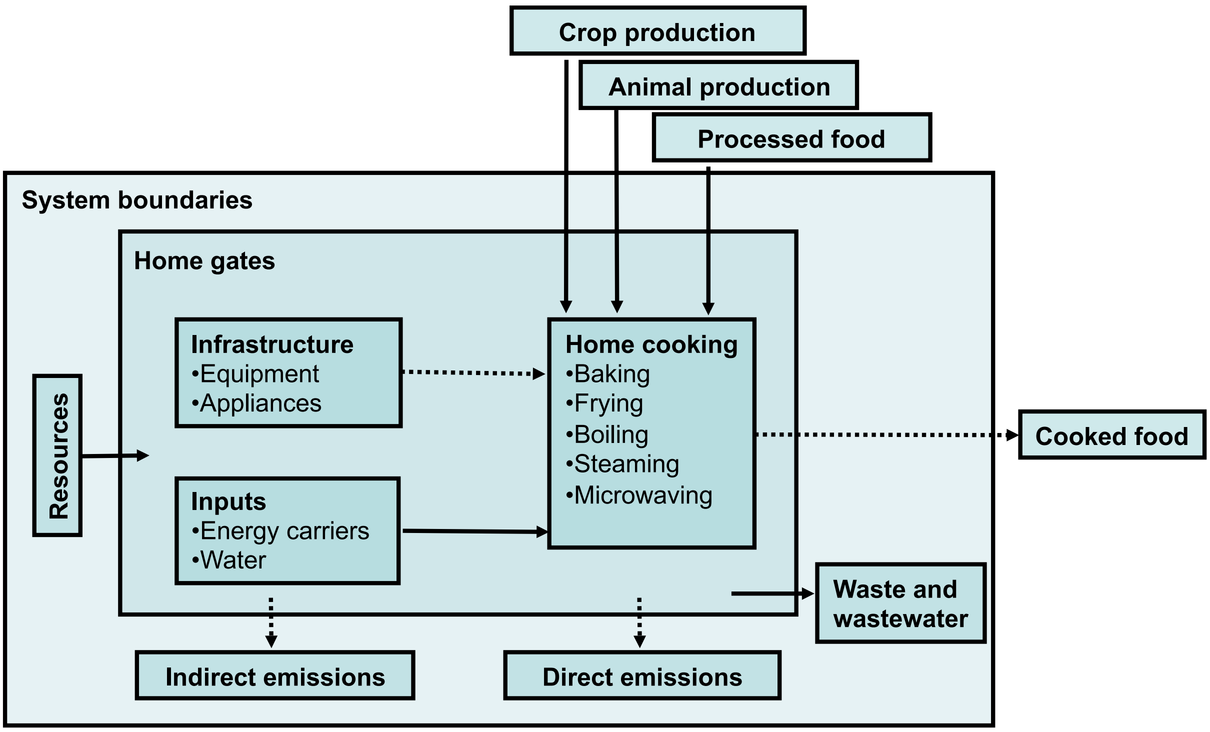

Figure 4: System boundaries for home cooking systems. Dotted arrows denote absence of transportation (or neglected)

Excluded processes are:

- Packaging, unless specifically mentioned (e.g. for mineral water)
- Distribution and refrigeration
- Labour and commuting
- Administrative work and R&D
- Cutlery and dishwashing
- Salt, oil, fat and spices (in home cooking)
- Processes that can reasonably be assumed to contribute to less than 1% of the environmental impact are excluded (cut-off criterion), when no data are available

2.5 Data representativeness

2.5.1 Geographical coverage

The World Food LCA Database aims to cover food production activities for a wide set of products and main net-exporting countries. The country scale is consistent with other LCI databases, such as ecoinvent, and provides a basis adapted to national regulations and average practices. Assessment of the whole variety of practices for cultivating a given crop in a same country is beyond the scope of the WFLDB project.

Principal producers and exporting countries for each commodity are identified through data of the Food and Agriculture Organization (FAO) (FAOSTAT data for years 2010-2017). National datasets are then combined into either set of global averages [GLO] for each product:

1. **Global market average**, where the volume (tonnage) exported annually for each country considered in the WFLDB is used as weighting factors. This is typically used for commodities that are purchased on the global market (e.g. maize grain, coffee beans or palm oil).
2. **Global production average**, where the volume (tonnage) produced annually for each country considered in the WFLDB is used as weighting factors. This average is typically used for products which are not sold on the global market (e.g. milk or asparagus)

2.5.2 Time

Data are representative of current average practices for crop production, animal production and food transformation. Temporal representativeness is especially important for factors that can potentially evolve quickly, such as:

- Crop yields
- Application of fertiliser and pesticides (amounts and types)
- Irrigation practices and requirements (as dictated by precipitation variability)
- Deforestation rates
- Electricity mixes
- Energy consumption for food transformation

As a general rule, multiannual data over the 4 more recent years (i.e. most frequently 2014-2017) are used. Exceptions are documented in the dataset documentation.

Other factors, such as infrastructure or machinery are assumed to be less time-dependant and can therefore rely on older data. This may also apply to background datasets from the ecoinvent database.

2.5.3 Technology

In alignment with attributional life cycle inventory databases, the average technology (or practice) is modelled (by opposition to marginal technology or best practice). In crop production, average practice should be understood as *conventional agriculture* as practiced by a majority of producers. When a specific technology or practice is modelled (e.g. organic production), this is explicitly mentioned in the name of the dataset.

Certified products are modelled in the WFLDB following the principles below:

- Detailed information on the certification scheme and specifications must be publicly available
- The certification scheme is critically evaluated and not considered itself a proof of more sustainable practice
- Certified products are modelled only if there is tangible proof that specifications are duly followed
- Modelling of certified products is performed on a case by case basis

2.6 Allocation

2.6.1 General principles

Agricultural production systems can provide multiple product outputs: usually one main product and one or several co-products or by-products. According to ISO 14044 (2006), multi-functional and multi-product systems should be solved with system expansion, or, when not possible, with allocation. The inputs and outputs shall be allocated to the different products according to clearly stated procedures. This methodological choice shall fit with the goal situations of the WFLDB.

ILCD-compliance requires differentiating by the archetype of goal situations A, B, or C (EU-JRC 2010a, p.87 and p.268). The WFLDB is of a purely descriptive character, i.e. represents current technologies used in different countries and based on average or generic data, and existing benefits and negative interactions with other systems are not considered. Thus, the WFLDB refers to goal situation C1.

Furthermore, WFLDB datasets do not consider changes on a macro level, i.e. process changes in background systems such as changes in the market structure of raw materials or energy carriers. Attributional modelling, with allocation used to deal with multifunctionality, is therefore adequate. According to the ILCD, in a first step the “physical causality” shall be considered and if not feasible “market price” shall be used as allocation criterion. WFLDB datasets can be used for several purposes and products and co-products of a production system can be used in different utilization pathways. A “physical causality” can only be derived for a specific utilization of product and co-products. Therefore, in WFLDB “physical causality” is used to define allocation criteria, when a utilization pathway of a product and co-products from a production system is known and clearly defined. If several potential uses exist, it is not possible to define one “physical causality” that fits for all potential applications and consequently, economic allocation criteria are applied in these cases. Such an approach is consistent with ISO 14044 (2006b).

2.6.2 Crop co-products

The use of products and co-products from crop production systems is not defined in an LCI database like WFLDB. For example, wheat can be used as food, feed or for production of bioethanol. Straw can either be used as bedding material, as feed, for combustion or for production of 2nd generation bioethanol. Different physical causalities would need to be applied in each of these cases; hence it is not possible to develop a single “physical causality” that fits for all potential applications.

Therefore, economic allocation has been found to be required and is used by default for crop co-products at the farm. Since only traded products and co-products are addressed, price information is available. Prices[3] are calculated as average values over 4 most recent years when available. This allocation rule applies to main products and co-product (e.g. for co-products at farm such as grains and straw, oil and press cake).

The economic allocation principle is also used for animal feed. Nguyen & van der Werf (2013) investigated the influence of the allocation rule for animal feed in carbon footprints of meat. Although for the single feed components the allocation rule is very important, on the level of meat, the influence is relatively small. Furthermore, the different co-products of the food and feed chains have different uses, so that a common physical causality is not applicable. For these reasons, the economic allocation is also used for animal feed. This is aligned with the European PEFCR on feed for food-producing Animals (FEFAC 2018).

2.6.3 Animal co-products at farm

In dairy farm systems, meat from surplus calves and cull dairy cows are obtained as co-products. Allocation based on physical causality is applied, following the guidelines from the International Dairy Federation (IDF 2015)[4]. This approach accounts for the feed energy demand, needed for producing milk and meat (dairy cow and calves), respectively. When all necessary parameters for a system-specific calculation are not available, the suggested default allocation of 12% to meat and 88% to milk (fat and protein corrected milk, FPCM) is applied, considering a BMR (ratio M_{meat}/M_{milk}) of 0.02 $kg_{meat}/kg_{milk.}$ This is aligned with the European PEFCR on dairy products (EDA 2018).

In June 2014, the European Commission launched an inter-sectorial working group (i.e. the *cattle model working group*) under the Product Environmental Footprint (PEF) initiative, aiming to define common modelling rules for cow products and co-products[5]. This effort led to the recommendation to apply the IDF (2015) allocation approach (EU-JRC 2015).

In sheep farms, coproducts have allocated burdens (meat and fibres). Economic allocation is applied by default to such systems.

In egg production systems, spent hens are obtained as co-products. These are generally either slaughtered for pet food or disposed of on-farm. Economic allocation is applied by default to such systems, and since the economic value of spent hens is in most cases negligible no allocation is needed, unless otherwise specified.

Guidelines from the Livestock Environmental Assessment and Performance Partnership (LEAP[6]) on feed, poultry, pigs and ruminants (ovine and bovine) supply chains may also be used to support allocation choices.

2.6.4 Animal co-products at slaughterhouse

Slaughtering is a typical multi-output process. In line with ISO 14040/ ISO 14044 economic allocation is appropriate because:

- the slaughtering process cannot be divided in separate sub-processes
- there are no products that could replace the co-products of slaughtering
- the product and the co-products don’t have a similar function

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[3] Prices are found case-by-case in published studies or online market data.

[4] The allocation method as recommended by IDF is a linear regression approximation (1-6.04*BMR) which works fine for BMR <= ca. 3%. For higher values this formula becomes biased, and an extreme case (BMR>16.5%) would result in negative allocation factors for milk. This is known and only affects a handful of datasets (with max BMR of 7.4%). A new version of the method will be proposed for future release.

[5] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

[6] FAO (2016a, 2016b, 2016c, 2016d and 2018). See www.fao.org/partnerships/leap/publications/en for most recent versions.

- the utilization of co-products can vary

At the slaughterhouse, the co-products in Tab. 2 are considered. Economic allocation is applied based on the PEFCR Guidance 6.3 (EC-JRC 2017) for beef and lamb, and 2014-2015 data from the European Fat Processors and Renderers Association (http://www.efpra.eu/), representative of a large share of European markets[7], for the other animals.

Tab. 2: Co-products from slaughtering

Beef	Pork	Chicken
Fresh meat	Fresh meat	Fresh meat
Food grade offal	Food grade offal	Food grade offal
Food grade bones	Food grade bones	-
Food grade fat	Food grade fat	-
-	-	-
-	Food grade blood	-
Cat. 3 slaughter by-products, including rind and blood	Cat. 3 slaughter by-products	Cat. 3 slaughter by-products
Hides and skins	-	-
-	-	Feathers
Cat. 1/2 materials and waste	Cat. 1/2 materials and waste	Cat. 1/2 materials and waste

The following definitions are used, in alignment with recommendations from the European PEF *cattle model working group*, Annex 2 (EU-JRC 2015).

a) Fresh meat and edible offal: The amounts of fat in the edible meat cuts vary among countries depending on the consumer preferences and cultural habits. Furthermore, the amount of offal used for food varies among countries, so averages are considered in WFLDB

b) Food grade bones: Excludes bones that are included in the fresh meat cuts.

c) Food grade fat: Excludes fat that is included in the fresh meat cuts.

d) Food grade rind: Excludes rind that is included in the fresh meat cuts

e) Food grade blood: Excludes blood that is included in the fresh meat cuts

f) Category 3 slaughter by-products: This group combines category 3 materials excluding category 3 hides and skins.

g) Hides and skins: This category includes hides and skins that are used for leather production.

h) Category 1 and 2 materials and waste: This includes materials that do not have market values at the slaughterhouse gate.

2.6.5 Co-products from dairy processing

Co-products from dairy processing are allocated based on their dry matter content, as per the guidance from the International Dairy Federation (IDF 2015) and the European PEFCR on dairy products (EDA 2018).

[7] EU prices are used for all markets, for simplicity reasons.

2.6.6 Transport and infrastructure

Allocation for use of means of transport and infrastructure (including slaughterhouses and storage facilities) is calculated as useful lifetime within the product system in relation to the total average useful lifetime.

3 Inventory modelling

3.1 Principles for data collection

3.1.1 Decision tree for identifying best data

Production inventories shall be based on the best data sources available referring to a specific commodity of a specific country. Figure 5 shows a hierarchical decision tree defining different data levels. This decision tree helps to identify the level of an available data source or in case that more than one source are available, defines which data source should be used. Starting from the top of the decision tree, the criteria for the highest data level (level 4 data) are defined. If no data meet these requirements, one shall check if the data fit the following level (level 3 data) and so on.

The following criteria are used to define data levels:

- The type of data (primary or secondary data)
- The degree of detail of the data (level of aggregation and specificity)
- The data representativeness of an average practice, according to section 2.5.3
- Whether the data are supported by an expert with demonstrated knowledge of the product in the country of interest.

In some cases, it is possible that different input categories of a same product use different data levels; for instance, input data on fertilisers might reach level 4 while pesticides data reach level 2 only. For full transparency, the data level per input category is part of the dataset documentation and is also reflected in the data quality assessment in accordance with section 4.2.

3.1.2 Definition of primary and secondary data

Primary data: L4 and L3 (see Figure 5) refer to primary data, i.e. data with low level of aggregation retrieved from original studies such as scientific research, surveys, case studies, or monitoring data, if it can be reasonably assumed that such data are describing a representative production system in the respective country. Furthermore, original L1 and L2 data endorsed by experts are considered as L3 or L4 data.

Secondary data: L2 and L1 (see Figure 5) refer to secondary data, i.e. generic data that are aggregated in some way. Typical secondary data are official statistics such as FAOSTAT or EUROSTAT and results from estimation models that are based on such data sources. In general L1 data should be available for all datasets. However, when no L1 data are available, data for a similar product or similar country from an existing LCI database shall be used as a proxy; such data are defined as L0 data (Figure 5).

3.1.3 Defining input categories

Data collection addresses the following input categories at least:

- Crop production: fertilisers, pesticides, machinery and irrigation and drying where relevant
- Animal production: feed, infrastructure, water use
- Food processing: milling, roasting, grinding, cutting, extracting, slaughtering, pasteurising, ancillaries input, etc.

3.1.4 Definition of degrees of detail

Three degrees of detail for production inputs and outputs are defined as follows:

- **Low detail** (level 1 data) = production inputs are addressed per input category as a total, e.g. total kg of mineral fertiliser per nutrient; or total kg of feed.

- **Medium detail** (level 2 and 3 data) = production inputs of one category such as fertiliser or feed are given for at least two types, e.g. N-fertiliser and P-fertiliser; or roughage feed and concentrate feed.
- **High detail** (level 4 data) = different production inputs within an input category are distinguished, e.g. N ammonium nitrate and N urea (for N-fertilisers); or wheat-based and maize-based concentrates (for concentrates feed).

Appendix 6.2 describes the levels of detail for crops-related production inputs.

3.1.5 Definition of expert consultation

Experts with known experience on specific crop production practices in specific countries have to be involved when primary data (level 3 and level 4) are used. Experts comment primary data sources with regard to the objectives of WFLDB. Experts may also provide access to additional primary data, such as technical reports published in other languages than English.

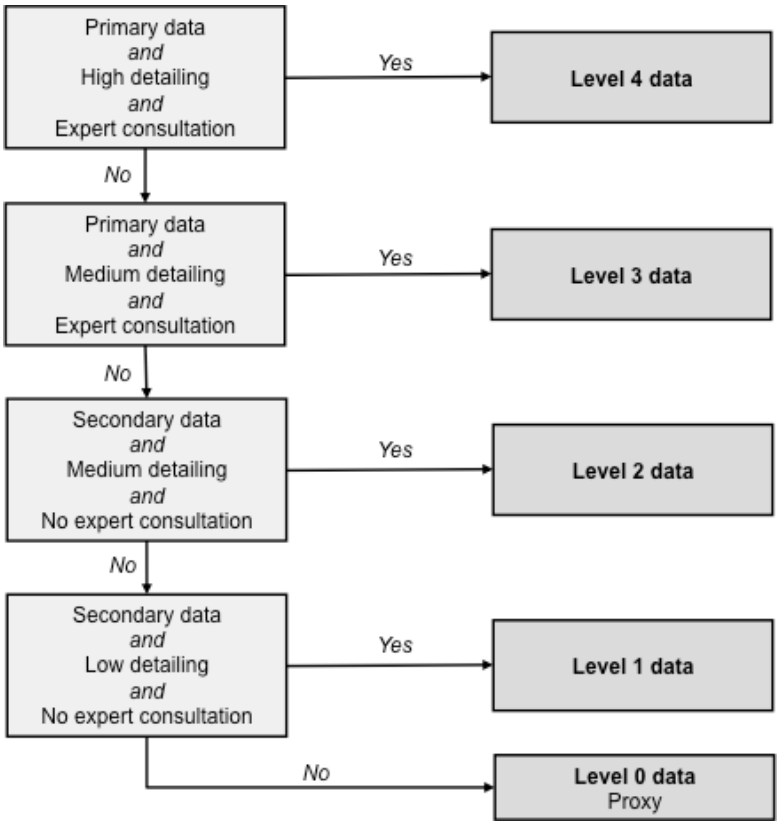

Figure 5: Decision tree for identifying the best available data for production inventories

3.2 Yield

3.2.1 Crop products

Accurate data about yield is fundamental to the life cycle inventory of crop products, since it directly impacts the functional unit, as well as the amounts of relevant production inputs such as fertiliser, pesticides, irrigation, and machinery.

If no level 4 or level 3 data are available, the following principles for generic data of level 1 and level 2 is applied:

Level 1 data for yield

Yield of fresh matter per hectare is taken from FAOSTAT using a recent average of four years (e.g. 2012-2015 or 2014-2017) per product and country. Standard values for water content and carbon content of the harvested product(s) are used for all countries. The same applies to the amount of straw and haulms per hectare, which are required for an accurate estimation of the fertiliser demand and for the calculation of specific emissions. For cereals the harvest-index, which expresses the ratio of grain to straw, shall be used.

Level 2 data for yield

Yield of fresh matter per hectare refers to specific products that are commonly sold on national or international markets. Yields from production systems that are usually not sold on the market are not considered (e.g. subsistence agriculture). If a dataset is representative of conventional production, yields from organic production systems are excluded whenever possible. Level 2 data for yield refer as far as possible to specific system parameters such as soil and climate conditions, production techniques (e.g. till or no-till; glasshouse or open field), crop rotation (or monoculture) and deforestation.

3.2.2 Animal products

For animal products, the functional unit refers to live weight at farm, respectively fresh meat at slaughterhouse. Yields are correlated to the daily weight gain and age at slaughtering. All these parameters are documented within the datasets.

For milk, the functional unit refers to 1 kg FPCM (see section 2.3). The milk yield per cow and lactation is systematically documented. Where animal fibre is the main product from animal production, the functional unit is greasy weight (as shorn off the animals) at the farm gate or clean weight after it leaves a scouring plant.

Level 1 data are taken from FAOSTAT (average production per animal).

Level 2 data distinguishes between conventional and organic production as well as production for the domestic market and for exports, whenever possible.

3.3 Land transformation

3.3.1 Definitions: direct and indirect land use change

Land transformation is a change from one land use type to another as a result of a human activity. The amount of land transformed is the area required to produce 1 functional unit of a product. Land use change has impacts on soil properties (e.g. carbon content or compaction among others), , nutrients leaching, N_2O emissions on biodiversity, on biotic production (Brandão and Milà i Canals 2012; Koellner *et al.* 2013; Koellner *et al.* 2012) and on other environmental aspects such as landscape, albedo and evapotranspiration (Spracklen *et al.* 2012).

Direct (dLUC) and indirect (iLUC) land use changes are often distinguished. Direct land use change can be defined as a change directly related to the history of the piece of land occupied. Indirect land use change can be defined as a change that appears in a different area than the direct land use as an indirect consequence. Typical example of iLUC is the increase of soybean production in Brazil that forces cattle production to move to other regions, where deforestation tends to increase as a consequence of increased pressure on land (Lapola *et al.* 2010). There is no international consensus on how to consistently and systematically address LUC in life cycle inventory, despite significant research in the LCA community (Bauen *et al.* 2010; Beuchle R *et al.* 2015; Curtis *et al.* 2018; De Rosa M 2018; De Rosa M *et al*. 2017a; De Rosa M *et al*. 2017b; De Rosa M, 2016; De Sy V *et al*. 2015; Fritsche *et al*. 2010; Henders S *et al*. 2015; Nassar *et al*. 2011; Novaes RML *et al*. 2017; Peters D *et al.* 2016; Saez de Bikuña K *et al*. 2018; Schmidt 2008; Searchinger *et al*. 2008; Sylvester-Bradley 2008; Tipper *et al*. 2009; Tubiello FN *et al*. 2014).

Therefore, in the WFLDB, no formal difference is made between dLUC and iLUC. The statistical land use change calculated case by case is called sLUC and can be considered as a proxy for iLUC and a best guess for iLUC.

3.3.2 Land use change from crop production

In crop production, global land transformation impacts are mainly driven by deforestation of primary forests. However, land use change from secondary forest or grassland to arable land must also be addressed in the inventory. Land use change from perennial to annual crops is also assessed.

LUC from crop production follows the methodology described by the Greenhouse Gas Protocol (Bhatia et al. 2011). The quantification of the land use change areas is based on annualized, retrospective data of the last 20 years (retrieved from FAOSTAT). All carbon pools are considered for all of the vegetation categories affected (Tab. 3).

In cases where the crop area in the country and its corresponding total land type area have increased in the considered time period, and if the area occupied by the natural ecosystem decreased during the same time period, the direct LUC is considered to be potentially relevant (Milà i Canals *et al.* 2012). Otherwise, if the crop area has decreased, LUC from a given land type is irrelevant to the life cycle inventory.

Two alternative approaches for allocating LUC are modelled. Both are country specific.

1. Crop-specific approach (default): land use change is allocated to all crops and activities that grew in the last 20 years in a given country, and only to them, according to their respective area increase. Crops which surface decreased are neither attributed any LUC impacts nor credits.
2. Shared-responsibility approach: land use change during the last 20 years is evenly distributed among all crops and activities present in the country, based on current area occupied.

For the default allocation, calculation of the area of land transformed per hectare of crop is computed with a Microsoft Excel tool[8] developed to support the estimates of LUC emissions based on the PAS 2050-1 / GHG Protocol / ENVIFOOD protocol approach. This tool has been developed by Blonk Consultants in 2013 and has been modified by Quantis to comply with WFLDB's requirements[9] and updated with more recent data. It uses statistical data for crops production and natural land areas in all countries from 1995 to 2017 (FAOSTAT data for years 1990-2017), as well as for country climates and soil types (EU-JRC 2010c). The original version has been reviewed and approved by the World Resources Institute (WRI) for use in the GHG Protocol.

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[8] "Direct Land Use Change Assessment Tool", version 2014-1-21-january-2014. Initially available for download at www.blonkconsultants.nl

[9] Latest edition is "WFLDB2-adapted-Blonk 2014 direct-land-use-change-assessment-tool_2019-04-30.xlsx". Available upon request to Quantis. That version includes the following changes: Data update, including country names update. SOC-related emissions include peat drainage emissions in the whole World, when occurring; suppression of the "set-to-zero" policy when carbon capture occurs (inventory level); addition of more calculations and adaptation of the modelling structure for integration into the World Food LCA Database; correction of several crops definitions.

To attribute LUC associated with the increase in area of each crop, a time period of 20 years is used for the calculation of the average annual increment. The same time period is applied for the amortisation of the emissions, which is aligned with PAS 2050-1 (BSI 2011a, BSI 2011b), FAO guidelines for feed supply chains (FAO 2016a) and ecoinvent V3.0 (Nemecek *et al.* 2014).

Four kinds of carbon pools – aboveground biomass (AGB), belowground biomass (BGB), dead organic matter (DOM) and soil organic carbon (SOC) – and four categories of vegetation – primary forest, secondary forest, grassland and perennial cropland – are considered. The values for the relevant carbon pools are taken from the IPCC Agriculture, Forestry and Other Land Use (AFOLU) report (IPCC 2006) and FAO (2010), Annex 3, Table 11.

For land transformation from primary forest and secondary forest, it is assumed that 20% of the AGB is burned and 8 % harvested (Houghton *et al.* 2000). The BGB, the DOM and the remaining slash from the AGB decay. In other words, 92% of carbon stored in AGB, and 100% of BGB and DOM are transferred into the atmosphere as biogenic CO_2. This approach is in line with the default (tier 1) assumptions of the IPCC (IPCC 2006).

For land transformation from grassland, no harvest or burning of biomass is considered. 100% of AGB and BGB carbon is transferred into the atmosphere as biogenic CO_2. DOM is considered negligible.

Land transformation from perennial to annual cropland is also accounted for, using the above-mentioned “Direct Land Use Change Assessment Tool”.

For all categories of vegetation, change in SOC is accounted for in land occupation, since it is associated to the following land use category (section 3.4). SOC-related emissions from peat drainage are included (Joosten, 2010; IPCC, 2013)

Losses of SOC are accompanied by mineralization of N, which in turn leads to emissions of N_2O. To determine the amount of N mineralization, the C:N ratio has to be known. IPCC (2006) gives a default value of 15 for the conversion of forest or grassland to cropland. For cropland the value of 11 is used (see 3.9.7.2). The emission factor for N_2O from mineralized N is 1 % (kg N2O-N/kg N) (IPCC, 2006, Tab. 11.1, EF1).

Tab. 3: Carbon pools accounting in land transformation

Carbon pool	Land transformation				
	From primary forest	From secondary forest	From perennial crop	From annual crop	From grassland
AGB (1)	8% harvested and stored 92% emitted (20% burned, 72% by decay)			100% emitted by decay Net carbon capture may occur in certain cases (and is taken into account)	
BGB (2)	100% emitted by decay				
DOM (3)	100% emitted by decay			Ignored	
SOC (4)	SOC change according to IPCC 2006, including peat drainage emissions. Net carbon capture may occur in certain cases (and is taken into account)				

(1) Aboveground biomass; (2) Belowground biomass; (3) Dead organic matter; (4) Soil organic carbon

3.4 Land occupation

Measured in [m^2y], land occupation is calculated by multiplying the occupied area by time. Land occupation starts after the harvest of the previous crop (average harvest date) and ends with the harvest of the considered crop. If the date of the harvest of the previous crop is unknown, a period of 12 months is assumed, unless it is known that there is more than one cropping season per year. The previous crop is the last crop on the same field, where a physical product is harvested (previous main crop, catch crop for fodder or pasture) (Nemecek *et al.* 2011).

Impacts associated with land occupation result from changes in soil organic carbon (SOC) content, which results in the release of N_2O. The model is described in Nemecek *et al.* (2014) and is based on IPCC guidelines (2006).

3.4.1 Land management change effects on soil carbon

Within the same land use category, changes in management can occur with consequences on SOC contents. This concerns e.g. if the tillage intensity on cropland is reduced (plough → reduced tillage → no-till) or if organic manure is added on cropland, where no organic fertiliser was previously applied. In grassland systems, SOC can be increased by improving the management. These changes in SOC are only accounted for if there is a permanent change in management according to IPCC (2006, Table 5.5 for cropland and Table 6.2 for grassland). Land management changes are considered as land use changes. For cropland or grassland that is continuously managed in the same way (as it is e.g. the case for grassland and pasture without changes in management intensity), no change in SOC is calculated.

3.5 Water use

3.5.1 Water types for crop production

Typically, water use for crop production can be differentiated between:

- **Water withdrawal**: anthropogenic removal of water from any water body, either permanently or temporarily (ISO 14046:2014).
- **Consumed water**: water withdrawal where release back to the source does not occur, e.g. due to evaporation, evapotranspiration, product integration or discharge into a different drainage basin (ISO 14046:2014).
- **Green water**: the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil and vegetation. Eventually, this part of precipitation evaporates or transpires through plants (Hoekstra et al. 2011). This corresponds to the volume of rainwater consumed during the production process. For agricultural products, it refers to the total rainwater (from fields and plantations) that is evapotranspired, plus the water incorporated into the harvested crop.
- **Blue water**: fresh surface and groundwater used for irrigation.

Water flows modelled in the World Food LCA Database are:

1. Water withdrawal (input)
2. Water emitted to air (output)
3. Water emitted to surface water (output)
4. Water emitted to ground water (output)
5. Wastewater sent to treatment (output)

3.5.2 Irrigation water consumption

Water use is modelled following the ecoinvent V3.0 guidelines "Good practice for life cycle inventories - modeling of water use" (Lévová *et al.* 2012). Water use calculation for crop production is based on the consumed water (or blue water footprint) for different crops (Pfister *et al.* 2011) as a default.

In crop production, all consumed water is considered as irrigation water. Green water is not accounted for since it does not affect environmental impacts. Input irrigation water (i.e. water withdrawal) is calculated as:

$I_{withdrawal} = ET_{irr} / EF_{irr}$ [m^3/t]

With:

ET_{irr} = Evapotranspiration from irrigation [m^3/t]

EF_{irr} = Irrigation efficiency factor [-]

Evapotranspiration from irrigation is also known as consumed water or "blue water footprint". ET_{irr} for each crop are retrieved from Pfister *et al.* (2011), which provides average country-specific values for hundreds of crops. ET_{irr} is derived from the crop expected water consumption, calculated as the arithmetic mean of the full-irrigation water consumption (upper boundary) and the deficit water consumption (lower boundary).

ET_{irr} is based on an average yield in the considered country and is calculated in cubic meters of water per ton of harvested product [m^3/t].

The irrigation efficiency factor EF_{irr} depends on the irrigation technique and is calculated as follows (FAO 1989):

$EF_{irr} = Ea * Ec$ [-]

With:

Ea = Field application efficiency [-]

Ec = Conveyance efficiency [-]

The field application efficiency corresponds to the amount of water that is made available to the plant compared to the total amount being introduced in the irrigation system. This factor depends on the irrigation technique and is associated to losses due to evaporation.

The conveyance efficiency represents the efficiency of water transport in canals and depends on the canal length, the soil type in which the canals are dug and the level of maintenance of the irrigation system. Such information is field-specific and is therefore not addressed in an LCI database of average crop production systems.

Default values are used for the field application and conveyance efficiency (Tab. 4).

Tab. 4: Irrigation efficiency EF_{irr} (adapted from FAO 1989)

Irrigation technique	Field application efficiency (Ea) [-]	Conveyance efficiency (Ec) [-]	Irrigation efficiency factor EF_{irr} [-]
Surface irrigation	0.60	0.75	0.45
Sprinkler irrigation	0.75	1.00	0.75
Drip irrigation	0.90	1.00	0.90

Since different irrigation techniques can be used for a same crop, the average irrigation efficiency is calculated based on their respective shares in each country. The following irrigation techniques are considered in the WFLDB:

- Surface irrigation: with gravity irrigation or by groundwater pumping; flood irrigation being special cases of surface irrigation.
- Sprinkler irrigation, or spray irrigation
- Drip irrigation, or micro-irrigation (this includes fertirrigation)

Level 1 data for shares of irrigation techniques

Country average shares (not crop-specific) as reported by the International Commission on Irrigation and Drainage (ICID 2012) in appendix 6.1. The cultivated area with surface irrigation is calculated as the total irrigated area minus the area with sprinkler irrigation, minus the area with micro irrigation.

Level 2 data for shares of irrigation techniques

Not applicable

Level 3 data for shares of irrigation techniques

Data from literature on specific crop (not country-specific).

Level 4 data for shares of irrigation techniques

Expert judgement or data from literature / real case studies / interviews on specific crop produced in a specific country.

Water source

Country-specific shares of groundwater, surface water and water from non-conventional sources (e.g. desalination) used for irrigation are retrieved from Siebert *et al.* (2010), as presented in appendix 6.1.

3.5.3 Irrigation energy use

Level 1 data for irrigation energy use

Total energy use for electricity and diesel are calculated. Energy use for pumping is dependent on numerous factors such as the water source (groundwater or surface water), the water depth (in the case of ground water), the pump power, pump speed, operating pressure, friction losses, etc. (Smajstrla *et al.* 2002). By simplification, a default energy consumption corresponding to pumping at an average depth of 48 m is considered (Tab. 5) and applied to both groundwater and surface water.

Tab. 5: Energy use for water pumping (depth = 48 m) (derived from UofA (2007) in Nemecek and Kägi 2007)

Alternative power supply	Energy use
Electricity	0.239 [kWh/m^3]
Diesel*	0.059 [l/m^3]

*Diesel density = 840 g/l

The following default assumptions are made when no better data are available:

1. Arable crops: no drip-irrigation, diesel powered,
2. Perennials: electricity powered in OECD countries, diesel powered in other countries,
3. Horticultural products, fruits and berries: electricity powered in OECD countries, diesel powered in other countries.

Electricity-powered pumps are modelled with country-specific datasets using the country electricity consumption mix. Diesel-powered pumps are generic.

The same energy use (per m^3 of irrigation water) is considered for all irrigation techniques (surface, sprinkler and drip), except for gravity surface irrigation (no energy use).

Level 2 data for irrigation energy use

Energy use from level 1 data are calculated. When such information is available, hand-activated or animal-activated pumps, involving no fuel or electricity use, are also considered. The same applies to gravity irrigation with reservoirs fed with surface or rainwater, which does not require pumping. Level 2 data leads to lower irrigation energy requirements compared to level 1 data.

Level 3 data for irrigation energy use

Data for irrigation energy use from the literature is used. Such data should be crop-specific and should refer to the different irrigation techniques (it is also country-specific for the type of electricity, when relevant, but not regarding the amount of energy).

Level 4 data for irrigation energy use

Expert judgement or data from literature relating to level 3 data, per crop and country.

3.5.4 Water emissions

Blue water (i.e. surface water and ground water) balance is achieved in the inventory. For crop production, three output flows are calculated:

- Water emitted to air = ET_{irr}
- Water emitted to surface water = $0.8 * ((ET_{irr} / EF_{irr}) - ET_{irr})$
- Water emitted to ground water = $0.2 * ((ET_{irr} / EF_{irr}) - ET_{irr})$

Equations are adapted from Lévová *et al.* (2012).

3.5.5 Animal production

Water use for animal production includes drinking water and cleaning water. Data are always taken from the literature or from expert judgement. For water release, when no specific data are available, 83% of water use is considered consumed (i.e. 17% is released) (Shaffer 2008). This approach is consistent with the Quantis Water Database (Vionnet *et al.* 2012).

3.5.6 Food transformation

Water use for food transformation includes processing water, cleaning water and cooling water. Data are always taken from the literature or from expert judgement. For water release, when no specific data are available, 12.2% of water use is considered consumed (i.e. 87.8% is released) (Statistics Canada 2007). This is not considered critical, since it is a small fraction of total water consumption in the food production. This approach is consistent with the Quantis Water Database (Vionnet *et al.* 2012).

3.6 Fertilisers application

3.6.1 Estimation of nutrient inputs

Nitrogen (kg N), phosphorus (kg P), and potassium (kg K) are taken into account as crop nutrients. If no level 4 or level 3 data are available, the following principles for generic data of level 1 and level 2 are applied:

Level 1 data for nutrient inputs

Nutrient input is calculated based on the nutrient uptake of the crop. For N, the harvested products plus crop residues, such as straw and haulms, are considered, even if the residues might remain on the field. This approach is based on the fact that N contained in the biomass is not readily available for crops, contrary to P and K. Therefore, for P and K, only products taken off the field are considered. For N, P and K the calculated nutrient uptake is assumed to be representative of the nutrient content of the crop and crop residues. The nutrient content values are crop-specific but not country-specific.

Level 2 data for nutrient inputs

Correction factors are applied to level 1 data. These take into account national surplus or deficit of fertilisers used. Such correction factors might be based on yield-adjusted fertiliser recommendations compared to nutrient uptake (level 1 data) and represent a "national nutrient balance". The International Fertilizer Association (IFA, www.fertilizer.org) and "Fertilizers Europe" provide statistics about fertiliser and nutrient consumption per country (worldwide) and, in case of Europe, also per crop. For extrapolation the MEXALCA approach is applied (Nemecek *et al.* 2012; Roches *et al.* 2010) using crop-specific data from an original country and extrapolate it by intensity indices to a target country.

3.6.2 Mineral and organic fertilisers, L1 data

We assume the ratio of N applied as mineral fertilisers to N total (organic and mineral fertilisers) to be 0.8 (Nemecek 2014b) for all crops and countries (L0). Based on this ratio and the total N applied as fertilisers, the amount of N applied as mineral fertilisers is calculated (crop and country-specific data).

In FAOSTAT (2017), the manure N content (kg N in manure) is provided per animal category on a country level (average from 2009-2012 was used). Based on these data, the share of liquid and solid manure per animal category and country is calculated, assuming 50% liquid and 50% solid manure for cattle, pigs and laying hens, and 100% solid manure for all other animal categories. In addition, the ratio of N in liquid to N in solid manure per country is calculated from these data.

Nutrient contents of manure (kg Nav/ kg P_2O_5/ kg K_2O per m^3 liquid and tonnes solid manure) are provided by Flisch et al. (2009) and presented in Tab. 6. These contents and the share of liquid and solid manure per animal category are used to calculate the average N, P and K content in liquid and solid manure for a specific country, assuming a dilution level of 50% for liquid manure.

Tab. 6: Default nutrient contents of manure as provided by Flisch et al. (2009)

Nutrient contents	Unit	World shares (scaled, from FAOSTAT 2010)	kg Ntot/unit	kg TAN/unit	kg Navailable/unit	kg P2O5/unit	kg K2O/unit	Comment	Category in GRUDAF09 (Flisch et al. 2009), Tab. 39
Liquid manure cattle	m3	63%	4.6	2.8	3.2	1.5	9.8	Undiluted	Mittelwert Milchvieh/Aufzucht: Vollgülle, Güllekotarm
Liquid manure fattening pigs	m3	23%	6.0	4.2	3.6	3.8	4.4	Undiluted	Schweinegülle Mast
Liquid manure sows and piglets	m3	3%	4.7	3.3	2.9	3.2	3.2	Undiluted	Schweinegülle Zucht
Liquid manure laying hens	m3	11%	21.0	6.3	10.5	17.0	11.0	Undiluted	Hennenkot (Kotband)
Liquid manure other	m3		6.8	3.5	4.1	3.8	8.5	Undiluted, values for cattle used, most important animal category	
Solid manure cattle	t	41%	5.1	1.1	1.7	2.7	8.7		Mittelwert Milchvieh/Aufzucht: Stapelmist, Laufstallmist
Solid manure pigs	t	17%	7.8	2.3	3.9	7.0	8.3		Schweinemist
Solid manure sheep and goats	t	13%	8.0	2.3	4.0	3.3	16.0		Schaf-/Ziegenmist
Solid manure horses	t	1%	6.8	0.7	1.3	5.0	19.5		Pferdemist
Solid manure laying hen litter	t	7%	27.0	7.0	13.5	30.0	20.0		Hennenmist (Kotgrube, Bodenhaltung)
Solid manure broiler litter	t	21%	34.0	10.0	17.5	20.0	28.0		Pouletmist
Solid manure other	t		13.7	3.8	6.6	9.2	14.6		

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

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

3.6.3 Estimation of mineral fertilisers input

If no level 4 or level 3 data are available, the following principles for generic data of level 1 and level 2 are applied:

Level 1 data for shares of mineral fertilisers input

Organic and mineral fertilisers are differentiated. The ratio of organic fertilisers relies on a common source or estimation method applicable to all countries; crop-specific data are only applied if available for all crops. FAOSTAT provides national data for the calculation of GHG emissions from animal husbandry. Among others, the manure N content (i.e. quantity of N applied to soil from manure) is provided per animal category. These values serve to calculate the average amount of animal manure applied per area in a country (not crop-specific).

The share of mineral fertiliser types per country is based on statistics provided by IFA (International Fertilizer Association, www.fertilizer.org).

Level 2 data for shares of mineral fertilisers input

Crop-specific information about organic and mineral fertiliser types per country are used when available. For some crops, specific types of fertilisers are recommended or discouraged. For mineral fertilisers, types used per crop are provided by IFA for European countries. For other countries crop-specific information might be obtained from literature or extrapolated from countries with comparable economic situation. For extrapolation the MEXALCA approach is applied (Nemecek *et al.* 2012; Roches *et al.* 2010) using crop-specific data from an original country, extrapolated by intensity indices to a target country.

3.7 Pesticides application

There are three types of pesticide data with increasing degree of detailing:

1) The total amount of active ingredient (a.i.) from any kind of pesticides
2) The total amount of a.i. used as herbicides, fungicides or insecticides
3) The amount of specific a.i.

By definition, literature or expert data about the amount of specific a.i. used represent L4 data, as these are at a high degree of detail. Literature or expert data about the total amount of a.i. used as herbicides, fungicides or insecticides as well as the total amount of a.i. from any kind of pesticide represent L3 data, owing to a lower degree of detail.

If no level 4 or level 3 data are available, the following principles for generic data of level 1 and level 2 are applied:

Level 1 data for pesticides input

The total amount of active ingredients (a.i.) used per hectare for a specific crop in a specific country are estimated applying the MEXALCA approach (Nemecek *et al.* 2012; Roches *et al.* 2010) that uses crop yield and intensity indices per country for pesticide use based on FAOSTAT data. A modified[10] formula is used as follows:

$$X_t^c = X_o^c \sqrt{\frac{ind_t^X}{ind_o^X}}$$

X_t^c: Amount of active ingredient in the target country (kg ha^{-1} year^{-1})
X_o^c: Amount of active ingredient in the original country (kg ha^{-1} year^{-1})
ind_t^X: Agricultural index in the target country for the intensity of use of input X (-)
ind_o^X: Agricultural index in the original country for the intensity of use of input X (-)

If no pesticide data are available for the target crop from a different country, the modified MEXALCA approach is applied with a different (but similar) crop than the target crop (e.g. apple for pesticide application in pear - L0 data).

Whenever the products used for plant protection are unspecified (i.e. when only the total amount of active ingredients is known), a default pesticide mix is used in the dataset modelling. This default mix is based on 2003 data published by the European Commission (European Commission 2007) [11]. Default mixes are established for the following crop families:

- Cereals
- Citrus
- Fruit tree
- Grapes and Wine
- Maize
- Oil seed

[10] The ratio of the yield in the target country to the yield in the original country is omitted, because there is no linear relationship between yield and the amount of pesticides applied.

[11] The use of plant protection products in the European Union, Data 1992-2003, 2007 Edition; European Commission

- Potato
- Sugar beet
- Vegetables

These mixes are split into datasets for *Herbicides unspecified*, *Fungicides unspecified*, *Insecticides unspecified* and *Pesticides unspecified*. The latter consists of a combination of the three others (percentages according to crop specific data). This results into 9x4=36 datasets.

All families of pesticides reported by the European Commission (2007) representing more than 4% of the total market share (for each crop and pesticide family) are considered in the mixes. The ratios are then recalculated such that all shares of the pesticide families above the threshold sum up to 100.

The pesticide families, as published by the European Commission, are then matched to ecoinvent input products of pesticide families based on structural similarity.

This method provides a consistent framework to model pesticides in LCA of agricultural products when the specific active substances are unknown. However, it does not necessarily represent the individual active substances with the highest market share, with substances such as glyphosate being possibly underrepresented in the set of emissions to soil.

This framework can easily be adapted when transparent data on the use of specific active substances for plant protection is published, as well as when similar data are published for other geographical regions.

Level 2 data for pesticides input

The amount of input per pesticide group (e.g. herbicides, insecticides, fungicides) used per crop and country is extrapolated from an existing dataset for a comparable country regarding agronomic and economic conditions. For the extrapolation the MEXALCA approach is applied (Nemecek *et al.* 2012; Roches *et al.* 2010) that uses yield and pesticide intensity indices. The degree of confidence of this extrapolation is documented, according to the data level that is used for the original country. The number of passes for pesticide application is estimated based on a similar extrapolation procedure. As background dataset for pesticides, “herbicide unspecified”, “insecticide unspecified”, and “fungicide unspecified” are used, as specified above.

The modelling of the pesticide emissions after application is described in Section 3.9.11.

3.8 Packaging

The following principles are applied:

- **Packaging for fertilisers:** standard package for dry fertilisers is included, i.e. 0.002 kg of HDPE per kg dry fertiliser; mass of 1 plastic bag for 50 kg solid fertiliser is 0.100 kg (measured data); assumption: 0.5 kg plant nutrients per kg dry fertiliser.
- **Packaging for pesticides:** standard package for liquid pesticides is included, i.e. 0.058 kg of HDPE per kg liquid agrochemical; mass of 1 bottle for 20 L is 1.16 kg (measured data); assumption: 0.5 kg active ingredient per kg liquid product.
- **Packaging for round bales at farm**: included (plastic net for hay, plastic wrapper for silage bales)
- **Packaging for food products**: excluded, unless specifically mentioned (e.g. mineral water)

Both the packaging material manufacturing and the packaging forming are included.

3.9 Direct emissions from crop and animal production

Direct field and farm emissions are substances emitted from an agricultural area or directly at the farm. Indirect emissions denote emissions that occur in the upstream processes, such as purchased inputs used in agriculture or transports. Direct emissions strongly depend on the site characteristics and are influenced by farm management practices. Indirect emissions are generally modelled with existing life cycle inventories, while specific models are generally used for direct emissions.

Emissions related to energy use such as fuels burnt at the farm are modelled similarly to indirect emissions for practical reasons.

3.9.1 Emissions included

For the agricultural phase the following direct emissions are modelled (using categories defined in the ecoinvent quality guidelines Weidema *et al*., 2013):

Emissions to air (non-urban air or from high stacks):

- Ammonia (NH_3)
- Dinitrogen monoxide or nitrous oxide (N_2O)
- Nitrogen oxides (NO_x)
- Methane, biogenic (CH_4)
- Carbon dioxide, biogenic
- Carbon dioxide, fossil
- Carbon dioxide, from land transformation
- Particulate matter ($PM_{2.5}$)
- Pesticides (if any applied)
- Water from irrigation (evapotranspired) or evaporated in processes

Emissions to surface water:

- Phosphorus, surface water (P from erosion)
- Phosphate, surface water (PO_4^{3-} from run-off)
- Heavy metals: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn)
- Water from irrigation

Emissions to groundwater:

- Nitrate (NO_3^-)
- Phosphate (PO_4^{3-})
- Heavy metals: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn)

Emissions to agricultural soil:

- Heavy metals: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn)
- Pesticides (if any applied)[12]

Further substances can be added, if relevant and if reliable data are available.

[12] For the modelling of pesticide emissions see Sections 3.7 and 3.9.11.

3.9.2 Overview of emission models

Tab. 7 gives an overview of the emission models that are used.

Emission models of similar level of detail and quality can be used in later updates of the database.

Tab. 7: Overview of the emission models used in the WFLDB.

Emission	WFLDB 3.5	Source
Ammonia (NH_3)	crops: EMEP Tier 2 animals: EMEP and IPCC (2006) Tier 2	EEA 2016 IPCC 2006
Nitrous oxide (N_2O)	IPCC (2006) crops: Tier 1 animals: Tier 2	IPCC 2006
Nitrate (NO_3^-)	SALCA-Nitrate (Europe) SQCB (other countries)	
Phosphorus (P, PO_4^{3-})	SALCA-P	Prasuhn 2006
Heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn)	SALCA method	Freiermuth 2006
Methane (CH_4)	IPCC (2006) Tier 2	IPCC 2006
Particulate matter (PM2.5)	EMEP Tier 2	EEA 2016

3.9.3 Ammonia (NH_3)

Several methods are available for the estimation of NH_3 emissions. The most widespread basis are the EMEP/EAA guidelines from the European Environment Agency, which are used to establish national emission inventories. The latest update of the methodology has been published in 2016 (EEA (European Environment Agency) 2016). The same methodology is also used in the AGRIBALYSE database (Colomb et al. 2014), with the difference that in AGRIBALYSE emission factors are taken from the EMEP/CORINAIR guidelines 2006 (EEA 2006), which represent a simplified approach. The ecoinvent V3.0 uses the Swiss Agrammon model for Swiss agricultural inventories, which is similar, but more detailed especially in the area of emissions from animal husbandry. The Agrammon model is a Tier-3 methodology for Switzerland and provides a number of correction factors, which can be used to represent specific situations. In the international context of the WFLDB, the EMEP/EAA guidelines are followed.

3.9.3.1 Crop Production

The emission factors for mineral fertilisers are taken from the EMEP guidelines 2016 (EEA (European Environment Agency) 2016).

Tab. 8: Emission factors for NH_3 (expressed as kg NH_3-N per kg N applied) after the application of mineral N fertiliser in function of the soil pH.

	cool climate (cf. IPCC 2006)		temperate climate (cf. IPCC 2006)		warm climate (cf. IPCC 2006)	
Fertilizer type (m)	EFa kgN/kg N soil pH<=7	EFb kgN/kg N soil pH>7	EFa kgN/kg N soil pH<=7	EFb kgN/kg N soil pH>7	EFa kgN/kg N soil pH<=7	EFb kgN/kg N soil pH>7
Ammonium sulphate (AS)	0.074	0.136	0.076	0.140	0.095	0.175
Ammonium nitrate (AN)	0.012	0.026	0.013	0.027	0.016	0.034
Calcium ammonium nitrate (CAN)	0.007	0.014	0.007	0.014	0.008	0.017
Anhydrous ammonia	0.016	0.029	0.016	0.030	0.021	0.038
Urea	0.128	0.135	0.131	0.138	0.163	0.173
Urea ammonium nitrate (UAN)	0.070	0.081	0.072	0.083	0.090	0.103
Di ammonium phosphate (DAP)	0.041	0.075	0.042	0.077	0.053	0.096
Mono ammonium phosphate (MAP)	0.041	0.075	0.042	0.077	0.053	0.096
Other complex NK, NPK fertilizer	0.041	0.075	0.055	0.077	0.053	0.096
Urea ammonium sulphate (UAS)	0.101	0.135	0.103	0.139	0.129	0.174

Source: EMEP guidebook 2016 (EEA (European Environment Agency) 2016), part 3D: Crop production and agricultural soils, Table 3.2

The emission is calculated as follows:

NH_3 $= 17/14 * \sum_{m-1}^{M}\left(EFa_m * p + EFb_m * (1-p)\right) * N_{min,m}$

where

NH_3 = ammonia emission after mineral fertiliser application [kg NH_3]

m = fertiliser type (M = number of fertiliser types)

EFa_m = emission factor on soils with pH<=7 [kg NH_3-N/kg N] (see table above)

EFb_m = emission factor on soils with pH>7 [kg NH_3-N/kg N] (see table above)

p = fraction of soils with pH <= 7 [%/100]

N_{min} = mineral fertiliser application [kg N]

The conversion factor from N to NH_3 is 17/14.

3.9.3.2 Animal Production

The emission factors for animal housing (i.e. from manure on yard, manure storage, and manure deposited on pasture by grazing animals) are taken from the IPCC 2006 guidelines (nitrogen volatilization) and use the EMEP/EEA guidelines 2016 to determine the ratio between ammonia and nitrogen oxides emitted.

In manure management datasets, which are generic per animal and not specific to farm archetypes, the average N content per animal, taken from the literature such as ASAE (2005) and Nennich et al (2005), is used, as described in Tab. 9. The specific values for N content in manure, and hence the excreted N per functional unit, can be calculated from the feed intake for specific cases (see section 3.12.1), for practitioners who want to be more detailed.

Tab. 9: Average N content in manure dry matter, per animal.

Livestock	N content in manure	Source	Note
Unit	kg N kg^{-1} DM		
Cattle	0.045	ASAE 2005, Nennich 2005	Average between lactating cows and other animals (min 0.036, max 0.051 in Nennich)
Laying hen	0.073	ASAE 2005	
Poultry (broiler, turkey)	0.055	ASAE 2005	Average between animal categories
Sheep	0.034	Ogejo 2010	
Swine	0.070	ASAE 2005	Average between animal categories

ASEA: table 1b. Nennich: table 4. Ogejo: table 3.

The amounts of N added in straw are not taken into account in the model at this stage of development.

Emission factor for manure storage is based on the volatilisation fraction ($Frac_{GasMS}$) given by IPCC 2006, Tier II, Table 10.22. Assumption: 60% is emitted as NH_3 (based on proportions observed in EEA, 2016, 3.D Tab. 3.1). Proportions are calculated based on total N. Hence:

- 0.60 * $Frac_{GasMS}$ kg NH_3-N/kg total N in stored manure (urine and faeces)

Emission factor for manure on pasture is based on the volatilisation fraction ($Frac_{GasMS}$) given by IPCC 2006, Tier II, Eq 11.11, Table 11.3. 20% N volatilised as NH_3 or NO_X. Assumption: 60% as NH_3 (based on proportions observed in EEA, 2016, 3.D Tab. 3.1). Proportions are calculated based on TAN. Hence:

- 0.60 * $Frac_{GasMS}$ = 0.12 kg NH_3-N/kg TAN in deposited manure (urine and faeces). TAN = 0.6 total N (EMEP guidebook 2016 (EEA 2016), part 3.B: Manure Management, Table 3.9).

3.9.4 Nitrogen oxides (NO_x, NO, NO_2)

Nitrogen oxides stem mainly from the nitrification process. The importance of NO_x emissions from N fertiliser is relatively small compared to other sources. Therefore, simple emission factors are used. The emission factor for the application of mineral and organic fertiliser (including animal manure) is:

- 0.012 kg NO_x-N/kg N applied (EEA, 2016, 3.D Tab. 3.1, converted from NO_2 to N: 0.04*14/46 = 0.012)

The emission is calculated after subtraction of the N volatilized as NH_3. EEA (2016) expresses the emissions of NO_x as NO, while in ecoinvent NO_x is calculated as NO_2. In order to be compatible with the latter, the emissions is converted to NO_2. The conversion factor from N to NO_2 is 46/14.

Emission factor for manure storage is based on the volatilisation fraction ($Frac_{GasMS}$) given by IPCC 2006, Tier II, Table 10.22. Assumption: 40% is emitted as NO_X (based on proportions observed in EEA, 2016, 3.D Tab. 3.1). Proportions are calculated based on total N. Hence:

- 0.40 * $Frac_{GasMS}$ kg NO_x-N/kg total N in stored manure (urine and faeces)

Emission factor for manure on pasture is based on the volatilisation fraction ($Frac_{GasMS}$) given by IPCC 2006, Tier II, Eq 11.11, Table 11.3. 20% N volatilised as NH_3 or NO_X. Assumption: 40% as NO_X (based on proportions observed in EEA, 2016, 3.D Tab. 3-1). Proportions are calculated based on TAN. Hence:

- 0.40 * $Frac_{GasMS}$ = 0.08 kg NO_x-N/kg TAN in deposited manure (urine and faeces). TAN = 0.6 total N (see Tab. 9).

3.9.5 Nitrous oxide (N_2O)

Nitrous oxide (N_2O) is produced during nitrification and denitrification processes and is a very powerful greenhouse gas. For nitrous oxide we are following IPCC guidelines (IPCC, 2006) Volume 4 Tier 2 for animal production and Tier 1 for crop production.

3.9.5.1 Crop Production

More detailed models exist for the calculation of emissions from crop production (including application of manure). E.g. Hillier et al. (2011) use in the Cool Farm Tool[13] an adapted version of the regression model from Bouwman et al. (2002), which varies the emission rate in function of the rate of N application, crop type, soil texture, soil organic carbon, soil drainage, soil pH and the climate type. It is an interesting alternative for estimating N_2O emissions on field and farm scale. In the context of the WFLDB, national averages are considered. The influencing factors are quite difficult to estimate at national level (only the respective crop area should be considered). This would lead to using default values in most cases. Furthermore, it is an exponential equation. This means that using average values for the different factors in the equation could lead to biased results. A calculation for the different subset of conditions would be needed and a weighted average would need to be calculated from the resulting N_2O emissions. Given the complexity of this model and the risk of introducing bias, the chosen approach in the WFLDB is to use the IPCC (2006) Tier 1 factors:

N_2O = 44/28 * (0.01 (N_{tot} + N_{cr} + N_{som} + 14/17*NH_3 + 14/46*NO_x) + 0.0075 * 14/62*NO_3)

N_2O = emission of N_2O [kg N_2O ha^{-1}]

N_{tot} = total nitrogen in mineral and organic fertiliser [kg N ha^{-1}]

N_{cr} = nitrogen contained in the crop residues [kg N ha^{-1}]

N_{som} = nitrogen from mineralisation of soil organic matter [kg N ha^{-1}]

NH_3 = losses of nitrogen in the form of ammonia [kg NH_3 ha^{-1}]

NO_x = losses of nitrogen in the form of nitrogen oxides [kg NO_2 ha^{-1}].

NO_3 = losses of nitrogen in the form of nitrate [kg NO_3 ha^{-1}].

Note that the nitrate emissions could change in arid regions for rainfed crops or drip irrigation. This is not considered within the generic approach adopted.

N_2O released during decomposition of organic matter in the soil after land use change is a further source of emissions.

For flooded rice, the emission factor for direct emissions of N_2O is 0.003 (IPCC, 2006, Table 11.1, EF_{1FR}) instead of 0.01.

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[13] https://coolfarmtool.org

3.9.5.2 Animal Production

For the animal production, the emission factors from IPCC (2006) Tier 2 are used.

Direct emissions occurring during manure management are calculated based on IPCC 2006 Table 10.21. The emissions related to the nitrogen brought by the litter are not considered at this stage. The N_2O emissions from **grazing** are calculated based on IPCC 2006 Table 11.1:

- 2% of N excreted for cattle (dairy, non-dairy and buffalo), poultry and pigs
- 1% for sheep and other animals.

For all reactive N emissions (NH_3, NO_3, NO_x) from crop production and animal husbandry **induced emissions** are calculated. These are called “indirect emissions” in IPCC (2006), but as this term is misleading in the context of LCA, we use the term “induced emissions” instead. The induced emissions stem from nitrogen losses by volatilisation and leaching, calculated as follows:

- The nitrogen volatilisation fraction is given by IPCC 2006, Tier II, Tables 10.22 and 11.3.
- The leached fraction from manure on pasture is given by same Table 11.3.
- Leaching from manure management applies in the following cases: liquid/slurry and solid storage. In these cases, the leached fraction is based on FAO 2010, Table A2.4, and considering a proportion of cases where there is an excess of water. This proportion is assumed to be 20% in temperate countries and 40% in tropical countries.

The respective emissions factors are:

- 0.01 kg N_2O-N/kg NH_3-N resp. NOx-N (via volatilisation) and
- 0.0075 kg N_2O-N/kg NO_3-N (via leaching) (IPCC 2006, Table 11.3)

3.9.6 Methane (CH_4) emissions

Methane emissions from animal husbandry are calculated by the default methodology from IPCC (2006) Tier 2, which takes into account differences in feeding and production levels. In animal production datasets, the emissions from enteric fermentation and from manure management are separated from foreground emissions, to facilitate the interpretation of impact assessment results.

3.9.6.1 CH_4 from enteric fermentation

Enteric fermentation: $EF = \left[\frac{GE * \left(\frac{Ym}{100}\right) * 365}{55{,}65}\right]$ (Tier 2 method)

EF = CH4 emission [kg CH_4/head/year]

GE = gross energy intake [MJ/head/day]

Y_m = methane conversion factor [%GE converted to CH_4]

55.65 MJ/kg CH_4 = energy content of methane

Tab. 10: Methane conversion factors (Y_m) for the conversion of energy intake through feed into energy lost as CH_4. (IPCC, 2006, Tab. 10.12 and 10.13)

Animal category	Y_m ±1%	Source
Cattle (except feedlot fed)	6.50%	IPCC (2006), Tier 2
Cattle (feedlot fed)	3.0%	IPCC (2006), Tier 2
Pigs	0.60%	FOEN (2013)
Sheep (and goats)	6.50%	IPCC (2006), Tier 2
Lambs (<1 year old)	4.50%	IPCC (2006), Tier 2
Horses	2.50%	FOEN (2013)
Poultry	0.16%	FOEN (2013)

The Y_m factor poses a problem due to the value jump from 3% to 6.5% that occurs at an undefined point when the housing system is similar to feedlot in terms of feeding. Therefore, a linearized transition has been adopted in the cattle model, as illustrated by Figure 6, considering that the value of 3% is attained when the feed basket contains 90% or more concentrate feed (IPCC, 2006, Tab. 10.12). Cereals and compounds are considered concentrate feed.

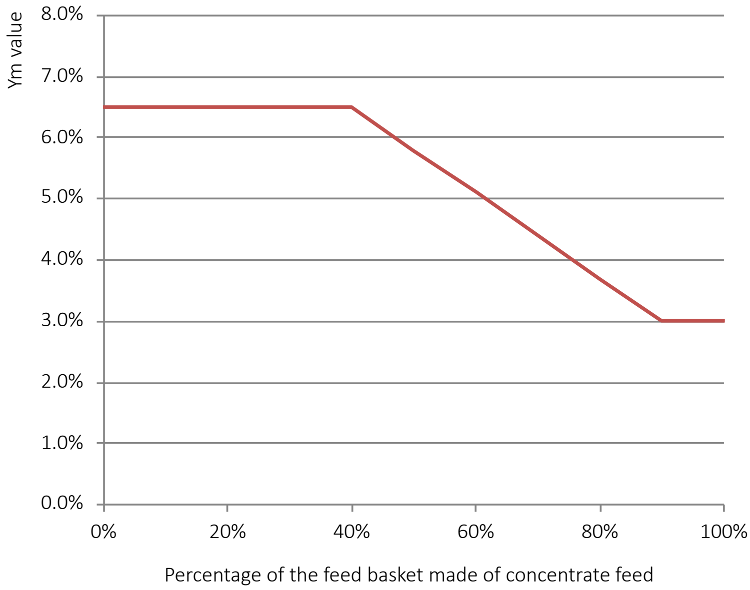

Figure 6: Linearized version of the Y_m parameter in the enteric methane emission formula

IPCC (2006) suggests applying Tier 2 emission factors only for cattle and sheep and Tier 1 factors for all other impact categories. For consistency reasons, we use Tier 2 factors for all animal categories, which are taken from the Swiss National Inventory report (FOEN, 2013).

When no better data are available, the GE intake can be estimated from DM intake, by using the default value of 18.45 MJ/kg DM from IPCC (2006).

3.9.6.2 CH_4 from manure management and grazing

$$EF_{(T)} = \left(VS_{(T)} * 365\right) * \left[B_{0(T)} * 0.67kg\Big/m^3 * \sum_{S,k} \frac{MCF_{S,k}}{100} * MS_{(T,S,k)}\right]$$

$EF_{(T)}$ = annual CH_4 emission factor for livestock category T [kg CH_4 animal^{-1} yr^{-1}]

$VS_{(T)}$ = daily volatile solid excreted for livestock category T [kg dry matter animal^{-1} day^{-1}]

365 = basis for calculating annual VS production [days yr^{-1}]

$B_0(T)$ = maximum methane producing capacity for manure produced by livestock category T, [m^3 CH_4 kg^{-1} of VS excreted]

0.67 = conversion factor of m3 CH_4 to kilograms CH_4

MCF(S,k) = methane conversion factors for each manure management system S by climate region k [%] (see Tab. 12)

MS(T,S,k) = fraction of livestock category T's manure handled using manure management system S in climate region k [dimensionless]

$$VS = \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left[\left(\frac{1 - ASH}{18{,}45}\right)\right]$$

VS = volatile solid excretion per day on a dry-organic matter basis [kg VS day^{-1}]

In practice, the amount of VS has been calculated as the dry matter content. In the present situation, this corresponds to an overestimation of methane emissions from manure roughly by a factor 1.05.

GE = gross energy intake [MJ day^{-1}]

DE% = digestibility of the feed in percent (e.g. 60%)

UE = urinary energy expressed as fraction of GE. Typically 0.04 GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Tab. 11: Maximum methane producing capacities for manure produced by livestock category.

Animal category	$B_{o(T)}$ (m^3 CH_4/kg VS excreted)
Other cattle	0.18
Beef fattening	0.18
Dairy cows	0.24
Cattle (average)	0.20
Lamb < 1 year	0.19
Turkey	0.36
Pigs	0.45
Broilers (chicken)	0.36
Laying hens	0.39

Tab. 12: Methane conversion factors for each manure management system for the cool climate, temperate and warm climates. Source: IPCC (2006, Tab. 10.17; for anaerobic digestion: Umweltbundesamt (2013, p. 288))

Categories IPCC (2006)	MCF Cool (<15°C)	MCF Temperate (15-25°C)	MCF warm (>25°C)
Pasture/Range/Paddock/Dry lot	1.0%	1.5%	2.0%
Daily spread	0.1%	0.5%	1.0%
Solid storage	2.0%	4.0%	5.0%
Liquid with natural crust cover[1]	10.0%	26.0%	48.0%
Liquid / slurry (without natural crust cover)[1]	20.0%	42.0%	75.0%
Uncovered anaerobic lagoon[1]	70.0%	78.0%	80.0%
Pit storage below animal confinements >1months[1]	20.0%	42.0%	75.0%
Anaerobic digester	2.0%	2.0%	2.0%
Cattle and swine deep bedding >1months[1]	20.0%	42.0%	78.0%
Composting (static pile)	0.5%	0.5%	0.5%
Poultry manure	1.5%	1.5%	1.5%

[1] More detailed MCF factors are given in IPCC (2006, Tab. 10.17). The medium values of each class are used here, i.e. the value for the following temperatures: 12°C for cool, 20°C for temperate and 27°C for warm climate.

3.9.6.3 CH_4 from rice cultivation

CH_4 emissions during rice cultivation are calculated according to IPCC (2006). The default baseline emission factor for non-flooded rice fields is 1.3 kg CH4 ha^{-1} d^{-1} (IPCC 2006, Tab. 5.11). This value is then adjusted according to the water regime during rice cultivation (IPCC 2006, Tab. 5.12), the water regime before rice cultivation (IPCC 2006, Tab. 5.13), and to organic amendments (IPCC 2006, Tab. 5.14).

The specific assumptions regarding the emission factors for the two producing countries considered in the database are as follows:

Tab. 13: Assumptions for the calculation of CH_4 emissions from rice cultivation

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

EQUATION 5.2
ADJUSTED DAILY EMISSION FACTOR

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_{s,r}$$

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)

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

Figure 7: Equation 5.2 of the IPCC 2006 Guidelines for the calculation of methane emissions from rice cultivation

Information regarding specific soil types or cultivar ($SF_{s,r}$) is not available in a workable solution at this stage. Based on these scaling factors and the baseline emission factor (EF_c is 1.30 kg CH_4 ha^{-1} d^{-1}), adjusted daily emission factors are calculated using equation 5.2 (IPCC 2006) above. These adjusted daily emission factors and the cultivation period are used in equation 5.1 (IPCC 2006) to calculate the methane emissions per hectare and per harvest, which are 71 kg and 219 kg in China and India, respectively. The lower amount of methane emitted from rice grown in China results from more specific data for this country as well as the fact that the crop cycle is significantly shorter. Rice in China is produced twice a year, whereas in India there is only one crop cycle per year.

3.9.6.4 CH_4 from crop residues

Methane emissions from crop residues during storage or being discarded are based on IPCC 2006 Guidelines for solid waste disposal (volume 5, chapter 3, equation 3.1). The main disposal options are listed in Tab. 15 below. The key parameters are the carbon content of the residues, the degraded fraction assumed under the specified conditions, the methane conversion factor (MCF) and the fraction F of CH_4 generated in landfill, when applicable.

Tab. 14: Crop residue management method and key parameters

Crop residue management method	Degraded fraction under these conditions	Methane conversion factor MCF	Fraction of methane F
Removed; left untreated in heaps or pits	15 - 50%	0.4	0.5
Removed; non-forced-aeration compost	25 - 75%	<0.1	0.5
Removed; forced-aeration compost	30 - 90%	<0.001	0.5
Left on field; incorporated or mulch	30 – 90%	Neglected	-
Burned	80 – 100%	Neglected	-

The carbon content depends on the crop residue itself. The degraded fraction is the fraction that can degrade of the degradable carbon (= DOC_f * DOC). DOC_f can be found or estimated based on literature. The MCF depends on the type of management and is taken from IPCC (2006).

Secondary parameters are the recovered fraction of methane R, which is generally nil in our cases, and the oxidation factor OX, which is also nil in our cases.

In the case of composting, a slight MCF can be considered based on Hermann et al (2011).

N_2O emissions are also calculated based on the total available nitrogen content of the residues and considering 0.05 kg N_2O-N per kg of degraded TAN (considering the same degraded fraction as for carbon), based on Hermann et al (2011). While IPCC (2006) considers N_2O emissions from solid waste disposal are “not significant”, the used assumption is rather high and reflects the large uncertainties encountered in crop residues management, often not managed in the best ways.

3.9.7 Nitrate leaching to ground water

Depending on the country of crop production, different models were used to calculate nitrate leaching. A model by Richner *et al.* (2014) specifically for the application to conditions in Switzerland (SALCA-NO_3) is applied for Europe. This model allows for a relatively detailed assessment of the processes during the cropping cycle. For non-European countries, the SQCB-NO_3 model, a geographically unspecific and simpler model, is used (de Willigen 2000, in: Faist Emmenegger *et al.* 2009).

Gaseous losses of NH_3, NO_x and N_2O are subtracted from the amount of N applied in the fertilisers prior to the calculation of nitrate leaching.

3.9.7.1 The SALCA-NO_3 model

Geographic scope of application: Europe

The model SALCA-NO_3 calculates the expected nitrate leaching and comprises the following elements (Richner *et al.*, 2014):

- Nitrogen mineralisation from the soil organic matter per month
- Nitrogen uptake by vegetation (if any) per month
- Nitrogen input from the spreading of fertiliser
- Soil depth

Factors that are not yet considered despite their potential importance:

- Amount of seepage
- Denitrification

The model of Richner *et al.* (2014) calculates the expected nitrate leaching of arable crops, meadows and pasture land considering crop rotation, soil cultivation, N fertilization but also N mineralisation from the soil organic matter, N uptake by the plants and various soil conditions. The calculation is based on the monthly difference between the amount of mineralised N in the soil and the N uptake by the plants. Furthermore, the nitrate leaching risk from fertiliser application varies in function of the time of N application and rainfall periods. The expected nitrate leaching of pastures rises because of locally high nitrate concentrations. Therefore, the total amount of nitrate on pastures is calculated from the number of animals, the grazing duration and the grazing period.

The total expected nitrate leaching of an arable crop is assessed by the sum of the monthly values within the assessment period starting one month after the harvest of the former crop and ending in the month of harvesting of the given crop.

Tab. 15: Expected nitrogen mineralisation within the SALCA-NO_3 model.

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Without intensive soil cultivation	0	0	6	9	12	15	17	21	23	12	6	0
With intensive soil cultivation	0	0	10	15	20	25	29	38	38	20	10	0

Expected nitrogen mineralisation ($N_{min\ m}$, kg N per ha and month, from Richner *et al*. 2014) in soils with 15% clay, 2% humus and N input from farm manure of 1 livestock unit (LU)/ha in the valley region. Intensive soil cultivation means treatment by a rotary cultivator or a rotary harrow in the respective month. In months where there is no intensive soil cultivation, the values “Without intensive soil cultivation” are used

N mineralisation is further corrected for clay and humus content of the soil (Tab. 16) as well as for green manuring and tillage of pastures (see Richner *et al.* 2014).

Tab. 16: Correction factors of nitrate mineralisation (%) for the clay and humus content of the soil.

		Humus content (%)			
		<3	3-5	5-8	8-15
Clay content (%)	0-20	0	+10%	+20%	+40%
	20-30	-10%	-5%	+5%	+25%
	30-40	-20%	-20%	-10%	+5%
	>40	-30%	-30%	-25%	-15%

N uptake by vegetation was estimated based on the model STICS (Brisson *et al.* 2003) with a high temporal resolution (100 time steps from sowing to physiological maturity of the crop in question). These N uptake functions were determined for the crops grass, protein peas, barley, potatoes, maize, rapeseed, soybeans, sunflower, wheat and sugar beets assuming for each crop a standard yield and a corresponding standard nitrogen uptake as given in Flisch *et al.* (2009). Nitrogen uptake by other crops is approximated by these functions or by combinations of them (see Richner *et al.* 2014). Variations in nitrogen uptake due to yields deviating from the standard yield were accounted for by scaling the nitrogen uptake relative to the difference between standard and real yields.

The N mineralisation from soil organic matter is further corrected for the average stocking rate, in order to reflect the conditions in farms with livestock. The basic values of nitrogen mineralisation which refer to 1 livestock unit (LU)/ha linearly decrease or increase with the stocking rate by 10% per 1 LU/ha.

The risk of nitrate leaching due to fertiliser application is dependent on the crop and the month in which fertiliser was applied (Tab. 17; Richner *et al*. 2014). The amount of N in mineral form (100% for the mineral fertilisers and varying percentages for the organic fertilisers) is the basis of the calculation. From this, the gaseous losses in form of NH_3, NO_x and N_2O are subtracted. The contents of mineral (soluble) N in organic fertilisers can be taken from Tab. 9 or from national sources like Flisch *et al.* (2009).

Tab. 17: Risk of nitrogen leaching (fraction of potentially leachable nitrogen of the N applied through fertilisers in %, from Richner *et al*. 2014).

Months	Winter cereals		Maize, soya beans	Winter rape seed and green manure		Potato, sugar and fodder beets	Fava beans, protein peas (spring sown)	Sun-flowers	Perma-nent meadow Int	Perma-nent meadow Ext
	sowing year	harvest-year	harvest-year	sowing year	harvest-year	harvest-year	harvest- year	harvest-year	calendar year	calendar year
January	100	50	100	100	20	100	100	100	20	20
February	100	30	100	100	10	100	100	100	10	20
March	100	10	100	100	0	50	50	50	0	0
April	100	0	80	100	0	30	30	30	0	0
May	100	0	70	100	0	10	0	0	0	0
June	100	0	0	100	0	0	0	0	0	0
July	100	-	0	100	-	0	0	0	0	0
August	100	-	0	80	-	0	-	0	0	0
September	90	-	0	0	-	0	-	-	0	0
October	90	-	-	0	-	-	-	-	0	0
November	90	-	-	20	-	-	-	-	10	20
December	90	-	-	20	-	-	-	-	20	20

The correction of the expected nitrate leaching due to fertiliser application for the depth of the soil is listed in Tab. 18. The loss rates can be up to 100%, when N is applied in periods when no N uptake takes place.

Tab. 18: The correction of the expected nitrate leaching due to fertiliser application in function of the depth of soil (Richner *et al.* 2014).

Soil depth (cm)	Correction (%)
> 100	0
91-100	+5
81-90	+10
71-80	+15
61-70	+20
51-60	+25
41-50	+30
≤ 40	+35

Generally, no seepage occurs during the intensive vegetation period because the evapotranspiration is similar or higher than the precipitation. Therefore, usually no nitrate leaching occurs during this period. For various crops fertilisation is only possible shortly before the growing period due to agronomic or technical reasons. The model accumulates the monthly values of N mineralisation, nitrate uptake by the plants and the nitrate from fertilisation during this period (Tab. 19). Values exceeding 100% are set to 100%.

Tab. 19: Accumulation of the monthly values of nitrate mineralisation, nitrate uptake by the plants and the nitrate from fertilising for various crops (Richner *et al*. 2014).

Crop	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Winter cereal				■	■	■						
Spring cereal					■	■	■					
Maize, soybean						■	■	■	■			
Potato					■	■	■	■				
Sugar beet, fodder beet					■	■	■	■	■			
Sunflower					■	■	■	■				
Fava bean, protein pea (spring sown)					■	■	■					
Fava bean, protein pea (autumn sown)				■	■	■						
Permanent meadow			■	■	■	■	■	■	■	■		

The grey cells show the periods during which the values of N mineralisation, N fertilisation and N uptake are added and the leaching risk is calculated from the sum of these values. In the white cells, the calculation is performed on a monthly basis.

As nitrate leaching is strongly dependent on the availability of water percolating the top soil which, in turn, depends on the precipitation, a correction factor is introduced. This nitrate leaching transformation factor represents the ratio of winter precipitations (October to March[14]) of the region in question and the site of Reckenholz (Switzerland, site of model calibration, where the average precipitation October-March is 433 mm) as most leaching occurs in this period. The results of SALCA-NO_3 are multiplied by the respective transformation factor.

3.9.7.2 The SQCB-NO_3 model

Geographic scope of application: Non-European countries.

The SQCB-NO_3 model is reported in Faist Emmenegger *et al.* (2009) and is an adaption of a formula developed by de Willigen (2000) and used and validated by Roy *et al*. (2003). The formula calculates the leaching of NO_3-N and is a simple regression model of the form:

$$N = 21.37 + \frac{P}{c * L}\left[0.0037 * S + 0.0000601 * N_{org} - 0.00362 * U\right]$$

where:

N	= leached NO_3-N	[kg N/(ha*year)]
P	= precipitation + irrigation	[mm/year]
c	= clay content	[%]
L	= rooting depth	[m]
S	= nitrogen supply through fertiliser	[kg N/ha]
N_{org}	= nitrogen in organic matter	[kg N/ha]
U	= nitrogen uptake by crop	[kg N/ha]

[14] Since the model is applied only to Europe, the Southern hemisphere does not need to be considered.

The SQCB model provides relatively simple approaches to assess most of the required input parameters. P and C_{org} are determined through the ecozone in which the crop is produced. The ecozones for the whole globe are defined and presented as maps in FAO (2001). Fix values for carbon content in the upper 30 cm of soil and for annual precipitation are assigned to each ecozone (see Tab. 20). More specific values can be used, where available. The carbon content in tonnes per 3000 m^3 (1 ha [area] * 30 cm [depth]) is converted into mass fraction by the formula:

C_{org} [%] = C_{org} [t/3000 m^3] * (1 / 1.3 t m^{-3}) * 100

In case of irrigation, the amount of irrigation water [mm] is added to the precipitation in order to obtain the parameter P. The amount of irrigation water is calculated according to section 3.5.2.

Where several ecozones are covered by the considered crop producing region, the model is applied to each ecozone and an average nitrate leaching rate for the whole producing region is calculated from the ecozone-wide results, weighted by the contribution of each ecozone to crop production – in terms of harvested acreage or production volume according to data availability.

Tab. 20: FAO ecozones and their assigned carbon content and annual precipitation. Due to high variability in precipitation, no values are given for montane ecozones. For these ecozones precipitation values have to be researched in each individual case. (From Faist Emmenegger *et al.* 2009)

FAO ecozones	Carbon content [t C/ha in upper 30cm= t/3000 m^3]	Annual precipitation [mm]
Tropical wet	59	2500
Tropical moist	48	1500
Tropical dry	34	1000
Tropical dry	34	500
Tropical dry	34	50
Tropical montane	55	-
Warm temperate moist	55	1200
Warm temperate dry	25	700
Warm temperate dry	25	400
Warm pemperate dry	25	200
Warm temperate moist or dry	40	-
Cool temperate moist	81	1500
Cool temperate moist	81	600
Cool temperate dry	38	300
Cool temperate dry	38	150
Cool temperate moist or dry	59	-
Boreal moist	22	500
Boreal dry	22	400
Boreal moist and dry	22	-

The clay content c is defined by the USDA soil order of a producing region or its sub-unit, respectively. A constant value for clay content is assigned to each USDA soil order based on USDA (1999) (see Tab. 21). The maps for defining sub-units of production regions or ecozones by soil orders are taken from USDA (1999), as well, and more detailed maps especially for the USA from the USDA website (http://soils.usda.gov/technical/classification/orders/).

Tab. 21: USDA soil orders and their assigned clay contents. (From Faist Emmenegger *et al.* 2009)

USDA soil order	clay content [%]
Alfisol	28.0
Andisol	10.4
Aridisol	17.2
Entisol	3.5
Gelisol	23.7
Histosol	2.0
Inceptisol	4.9
Mollisol	21.1
Oxisol	53.9
Spodosol	1.8
Ultisol	12.3
Vertisol	49.0

The rooting depth for several crops is given in the SQCB report by Faist Emmenegger (2009). The missing values were taken from other literature. Values and sources are presented in Tab. 22.

Tab. 22: Crops and their rooting depth as assumed for calculations.

Crop	Rooting depth [m]	Source
Potatoes	0.5	FAO 2011
Sugar cane	1.6	FAO 2011
Sweet sorghum	1.5	FAO 2011
Rape seed	0.9	SQCB report
Soybeans	0.95	FAO 2011
Oil palm	1.0	SQCB report
Wheat	1.2	FAO 2011
Maize	1.35	FAO 2011
Rice	0.6	Mishra *et al.* 1997
Cotton	1.35	FAO 2011

The nitrogen supply S is calculated from the total N application of mineral fertilisers and of soluble N in organic fertilisers after subtraction of the gaseous losses in form of NH_3, NO_x and N_2O. The original model sources (de Willigen, 2000; Roy *et al*. 2003) do not make a clear distinction between mineral and organic fertilisers. Since only the mineral (soluble) form of N is prone to leaching and for reasons of consistency with the SALCA-NO_3 model, only the soluble part of N in organic fertilisers is counted.

The nitrogen uptake U can be taken from Faist Emmenegger *et al.* (2009) or other sources (e.g. Flisch *et al*., 2009). Linear adjustments must be made for different yields. In the case of legumes, only 40% of the values given in the SQCB report are considered as N uptake in order to reflect the fact, that the remaining 60% are fixed from the air and are not directly relevant to the balance of nitrogen supplied through fertilisers and mineralised from the soil organic matter (Schmid *et al*. 2000).

To calculate the organic nitrogen N_{org} in soil [kg N/ha] from the soil organic carbon content C_{org} [%] the following quantities are needed:

- soil volume V [m^3/ha]

V is taken to be 5000 m^3, which means that the upper 50 cm of soil are considered (according to pers. comm. J. Leifeld, ART, 2011), assuming the same carbon content for 30-50 cm depth as calculated above for 0-30 cm depth.

- bulk density D_b [kg/m^3]

Bulk density is taken to be 1300 kg/m^3, which is the standard value from the SQCB report.

- C/N ratio $r_{C/N}$ [dimensionless]

The C/N ratio is taken to be 11. This is the mean value of the range (10-12) determined through literature research (Batjes 2008; Scheffer 2002; Eggleston *et al.* 2006) and consultation of experts (pers. comm. J. Leitfeld, Agroscope).

- ratio of N_{org} to N_{tot} (total soil nitrogen) r_{Norg} [dimensionless]

The C/N ratio expresses the ratio of C_{org} and N_{tot}. The ratio r_{Norg} is needed calculate N_{org} from

N_{tot}, which is calculated in a first step applying the C/N ratio. r_{Norg} is assumed to be 0.85 (Scheffer 2002).

- N_{org} is calculated by the formula:

$$N_{org} = \left(\frac{Corg}{100} \times V \times D_b\right) \div r_{C/N} \times r_{Norg}$$

N_{org} is the mass of organic nitrogen contained in the upper 50 cm of soil. Naturally only a fraction of this mass is mineralised and, hence, available for uptake by plants and leaching to the ground water. This fraction is determined by the mineralisation rate, which is 1.6% here and implicitly included in the regression coefficient (0.0000601) of the term N_{org}.

3.9.8 Phosphorus emissions to water

Three different pathways of phosphorus emissions to water are distinguished:

- leaching of soluble phosphate (PO_4) to ground water (inventoried as “phosphate, to ground water”),
- run-off of soluble phosphate to surface water (inventoried as “phosphate, to surface water”),
- water erosion of soil particles containing phosphorus (inventoried as “phosphorus, to surface water”).

Erosion by wind is not considered in these guidelines. However, in cases where wind erosion is important, it should be taken into account.

The emission models SALCA-P (Prasuhn 2006) developed by Agroscope are applied. The following factors are considered for the calculation of P emissions:

- type of land use
- type of fertiliser
- quantity of P in fertiliser
- type and duration of soil cover for the calculation of the soil erosion (C-factor).

For other factors, considered in the model SALCA-P, default values are used (Prasuhn 2006):

- distance to next river or lake
- topography
- chemical and physical soil properties
- drainage.

The model takes soil erosion, surface run-off and drainage losses to surface water and leaching to ground water into account.

The key factors of the model are listed below.

3.9.8.1 Phosphate leaching to ground water

P leaching to the ground water was estimated as an average leaching, corrected by P-fertilization:

P_{gw} = $P_{gwl} * F_{gw}$

P_{gw} = quantity of P leached to ground water [kg/(ha*a)]

P_{gwl} = average quantity of P leached to ground water for a land use category [kg/(ha*a)], which is:
0.07 kg P/(ha*a) for arable land and
0.06 kg P/(ha*a) for permanent pastures and meadows.

F_{gw} = correction factor for fertilization by slurry [dimensionless]

F_{gw} = $1 + 0.2/80*P_2O_{5sl}$

P_2O_{5sl} = quantity of P_2O_5 contained in the slurry or liquid sewage sludge [kg/ha]. The values of P_2O_5-content were taken from Flisch *et al.* (2009) or other national sources.

3.9.8.2 Phosphate run-off to surface water

Run-off to surface water was calculated in a similar way to leaching to ground water:

P_{ro} = $P_{rol} * F_{ro}$

P_{ro} = quantity of P lost through run-off to rivers [kg/(ha*a)]

P_{rol} = average quantity of P lost through run-off for a land use category [kg/(ha*a)], which is
0.175 kg P/(ha*a) for arable land,
0.25 kg P/(ha*a) for intensive permanent pastures and meadows and
0.15 kg P/(ha*a) for extensive permanent pastures and meadows

F_{ro} = correction factor for fertilization with P [dimensionless], calculated as:

F_{ro} = $1 + 0.2/80 * P_2O_{5min} + 0.7/80 * P_2O_{5sl} + 0.4/80 * P_2O_{5man}$
P_2O_{5min} = quantity of P_2O_5 contained in mineral fertiliser [kg/ha]
P_2O_{5sl} = quantity of P_2O_5 contained in slurry or liquid sewage sludge [kg/ha]
P_2O_{5man} = quantity of P_2O_5 contained in solid manure [kg/ha]

The values of P_2O_5-content for slurry and manure were taken from Flisch *et al*. (2009) or other national sources.

3.9.8.3 Phosphorus emissions through water erosion to surface water

P emissions through erosion of particulate phosphorous to surface water were calculated as follows:

P_{er} = $S_{er} * P_{cs} * F_r * F_{erw}$

P_{er} = quantity of P emitted through erosion to rivers [kg P/(ha*a)]

S_{er} = quantity of soil eroded [kg/(ha*a)]

P_{cs} = P content in the top soil [kg P/kg soil]. The average value of 0.00095 kg/kg was used.

F_r = enrichment factor for P (-). The average value of 1.86 was used (Wilke & Schaub 1996). This factor takes account of the fact that the eroded soil particles contain more P than the average soil.

F_{erw} = fraction of the eroded soil that reaches the river [dimensionless]. The average value of 0.2 was used.

The amount of eroded soil S_{er} is calculated using the universal soil loss equation as described in Faist Emmenegger *et al.* (2009), where the USLE (Universal Soil Loss Equation, Wischmeier and Smith 1978) is expressed as:

$S_{er} = 1000 * R * k * LS * c1 * c2 * P$

where

S_{er} = Potential long term annual soil loss [kg ha^{-1} yr^{-1}]

R = Erosivity factor [MJ mm ha^{-1} h^{-1} yr^{-1}]

k = Erodibility factor [t h MJ^{-1} mm^{-1}]

LS = Slope factor [-]

c1 = Crop factor [-]

c2= Tillage factor [-]

P = Practice factor [-]

The erosivity factor R is computed according to the LANCA methodology (Bos et al. 2016 LANCA characterisation factors for Life Cycle Impact Assessment, Version 2.0), which compiles a set of formula depending on the Köppen climate zone (Rubel F, Kottek M 2010).

Table 2 R-Factor approximation equations for the regarded climate zones

Climate zone	Equation	Source
Equatorial fully humid	$= -3172 + 7.562 * P$	(Mikhailava et al. 1995)
Equatorial monsoonal	$= -3172 + 7.562 * P$	(Mikhailava et al. 1995)
Equatorial summer dry	$= -669.3 + 7 * P - 2.719 * E$	(Mikhailava et al. 1995)
Equatorial winter dry	$= -3172 + 7.562 * P$	(Mikhailava et al. 1995)
Arid desert cold arid	$= 0.809 * P^{0.957} + 0.000189 * S^{6.285}$	(Naipal et al. 2015)
Arid desert hot arid	$= 0.0438 * P^{1.61}$	(Yu and Rosewell 1996)
Arid steppe cold arid	$= 10^{(0.0793+0.887 * \log(P) + 1.892 * \log(S) - 0.429 * \log(E))}$	(Naipal et al. 2015)
Arid steppe hot arid	$= 10^{(-7.72+1.595 * \log(P) + 2.068 * \log(S))}$	(Naipal et al. 2015)
Warm temperate fully humid hot summer	$= 10^{(0.524+0.462 * \log(P) + 1.97 * \log(S) - 0.106 * \log(E))}$	(Naipal et al. 2015)
Warm temperate fully humid warm summer	$= 10^{(-7.694+4.1407 * \log(P) - 2.586 * \log(S))}$	(Naipal et al. 2015)
Warm temperate fully humid cold summer	$= 10^{(-7.694+4.1407 * \log(P) - 2.586 * \log(S))}$	(Naipal et al. 2015)
Warm temperate summer dry hot summer	$= -944 + 3.08 * P$	(Cooper 2011)
Warm temperate summer dry warm summer	$= 98.35 + 3.55 * 10^{-4} * P^{1.987}$	(Naipal et al. 2015)
Warm temperate summer dry cold summer	$= -944 + 3.08 * P$	(Cooper 2011)
Warm temperate winter dry hot summer	$= -3172 + 7.562 * P$	(Mikhailava et al. 1995)

Climate zone	Equation	Source
Warm temperate winter dry warm summer	$= -3172 + 7.562 * P$	(Mikhailava et al. 1995)
Warm temperate winter dry cold summer	$= -3172 + 7.562 * P$	(Mikhailava et al. 1995)
Snow fully humid hot summer	$= 10^{(-1.99+0.737 * \log(P) + 2.033 * \log(S))}$	(Naipal et al. 2015)
Snow fully humid warm summer	$= 10^{(-0.5+0.266 * \log(P)+3.1 * \log(S)-0.131 * \log(E))}$	(Naipal et al. 2015)
Snow fully humid cold summer	$= 10^{(-1.259+3.862 * \log(S))}$	(Naipal et al. 2015)
Snow fully humid extremely continental	$= 10^{(-1.259+3.862 * \log(S))}$	(Naipal et al. 2015)
Snow summer dry hot summer	$= 10^{(1.882 + 0.819 * \log(P))}$	(Naipal et al. 2015)
Snow summer dry warm summer	$= 10^{(2.166+0.494 * \log (P))}$	(Naipal et al. 2015)
Snow summer dry cold summer	$= 10^{(4.416 + 0.0594 * \log(P))}$	(Naipal et al. 2015)
Snow summer dry extremely continental	$= 10^{(4.416 + 0.0594 * \log(P))}$	(Naipal et al. 2015)
Snow winter dry hot summer	$= 38.5 + 0.35 * P$	(Lee and Lee 2006)
Snow winter dry warm summer	$= 38.5 + 0.35 * P$	(Lee and Lee 2006)
Snow winter dry cold summer	$= 10^{(1.882 + 0.819 * \log(P)}$	(Naipal et al. 2015)
Snow winter dry extremely continental	$= 10^{(1.882 + 0.819 * \log(P))}$	(Naipal et al. 2015)
Polar polar frost	$= 10^{(-10.66 + 2.43 * \log(P))}$	(Naipal et al. 2015)
Polar polar tundra	$= 10^{(-10.66 + 2.43 * \log(P))}$	(Naipal et al. 2015)

Where:
P = Average annual precipitation [mm/year]
E = Mean elevation [m]
S = Average annual precipitation / number wet days [mm/day]

The LS factor computation is based on the original equation described in Wischmeier and Smith (1978). The only adjustment consists in transforming the input data from the SI (International System of Units) units to the American metric system. Indeed this formula requires length in feet whereas the user types it in in meters.

$$LS_i = \begin{cases} \left(\frac{\mathrm{L_i} * 3.28083}{72.6}\right)^{0.2} * (65.41 * (\sin(\frac{S_i}{100}))^2 + 4.56 * (\sin(\frac{S_i}{100})) + 0.065) & if \quad S_i < 1\% \\ \left(\frac{\mathrm{L_i} * 3.28083}{72.6}\right)^{0.3} * (65.41 * (\sin(\frac{S_i}{100}))^2 + 4.56 * (\sin(\frac{S_i}{100})) + 0.065) & if \quad 1\% \le S_i < 3.5\% \\ \left(\frac{\mathrm{L_i} * 3.28083}{72.6}\right)^{0.4} * (65.41 * (\sin(\frac{S_i}{100}))^2 + 4.56 * (\sin(\frac{S_i}{100})) + 0.065) & if \quad 3.5\% \le S_i \le 5\% \\ \left(\frac{\mathrm{L_i} * 3.28083}{72.6}\right)^{0.5} * (65.41 * (\sin(\frac{S_i}{100}))^2 + 4.56 * (\sin(\frac{S_i}{100})) + 0.065) & \mathrm{if} \quad \mathrm{S_i} > 5\% \end{cases}$$

Where S_i is the slope of the segment i expressed in %, L_i is the length of the segment i expressed in meters and LS_i is the partial slope factor for the segment i. The factor 3.28083 is a conversion factor from meter to feet and 100 is a conversion factor related to the fact that the slope is expressed in %.

LS is then computed as the sum of all LS_i:

$$LS = \sum_{i=1}^{n} LS_i$$

Where n is the number of segments. In the WFLDB, only one segment will be considered as default.

The K factor is calculated either from the Table 7-2 given by Faist Emmenegger *et al.* (2009) or taken from Table 5 in Panagos et al. (2014) for European countries and Table 4 for other countries, where the information about the soil class is not available (only the clay and sand content needed).
The c1 factor is taken from Table 7-3, c2 the factor from 7-4 and the P factor from Table 7-5 in Faist Emmenegger *et al.* (2009) or from other literature (e.g.: Panagos et al. 2015).

3.9.9 Heavy metals emissions to agricultural soil, surface water and ground water

Heavy metals exchanges in agriculture is a complex issue still under development. The approach below is proposed until better approaches could be provided. According to an analysis of the heavy metals[15] that are causing problems in agriculture (Kühnholz 2001), the following seven were selected:

- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Lead (Pb)
- Mercury (Hg)
- Nickel (Ni)
- Zinc (Zn)

No distinction is made between Cr(II) and Cr(III), only the sum of Cr flows is considered.

[15] Heavy metals are metals with a specific weight greater than 5 g/cm^3 (Source: http://chemistry.about.com/od/chemistryglossary/g/Heavy-Metal-Definition.htm).

Typical heavy-metal content of agricultural and non-agricultural soils is given by Desaules & Dahinden (2000). Kühnholz (2001) gives a comparison of different emission factors and methods for calculating heavy metal balances.

The heavy metal emissions are calculated by SALCA-heavy metal (Freiermuth 2006). Inputs into farm land and outputs to surface water and groundwater are calculated on the basis of heavy metal input from seed, fertiliser, plant protection products and deposition from the air. Crop residues left on the field are not considered, since they do not leave the system. Average heavy metal contents for arable land, pastures, meadows and horticultural crops are used to calculate the amounts of heavy metals exported by soil erosion. The amount of eroded soil is the same as calculated for the P-emissions (see above). An allocation factor is used to distinguish between diffuse and agriculture-related introduction (Freiermuth 2006).

Three types of emissions are considered:

- Leaching of heavy metals to the ground water (always positive values)
- Emissions of heavy metals into surface waters through erosion of soil particles (always positive values)
- Emissions of heavy metals to agricultural soil (positive or negative values according to the results of the balance).

The following sources are used to calculate heavy-metal contents:

- Mineral fertiliser: Desaules & Studer (1993, p. 153), see Tab. 27,
- Farmyard manure: Menzi & Kessler (1998) and Desaules & Studer (1993, p. 152), see Tab. 28,
- pesticides: FOAG (2014),
- biomass (seed and products from plant production): Houba & Uittenbogaard (1994, 1995, 1996 & 1997), von Steiger & Baccini (1990) and Wolfensberger & Dinkel (1997); Bennett et al. (2000) & for Nickel Teherani (1987) for rice; generic mean of biomass for cotton due to lack of data with mass allocation to fibre and seed (Freiermuth 2006); see Tab. 26.

Heavy metal emissions into ground and surface water (in case of drainage) are calculated with constant leaching rates as:

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

$M_{leach\ i}$ agricultural related heavy metal *i* emission

$m_{leach\ i}$ average amount of heavy metal emission (Tab. 23)

A_i allocation factor for the share of agricultural inputs in the total inputs for heavy metal *i*

Tab. 23: Heavy metal leaching to groundwater according to Wolfensberger & Dinkel (1997).

Leaching	Cd	Cu	Zn	Pb	Ni	Cr	Hg
mg/ha/year	50	3600	33000	600	n.a.	21200	1.3

Heavy metal emissions through erosion are calculated as follows:

$M_{erosion\ i} = c_{tot\ i} * S_{er} * a * f_{erosion} * A_i$

$M_{erosion}$ agricultural related heavy metal emissions through erosion [kg ha^{-1} a^{-1}]

$c_{tot\ i}$ total heavy metal content in the soil (Keller & Desaules 2001, see Tab. 24 [kg/kg])

S_{er} amount of soil erosion (see section 3.9.8.3) [kg ha^{-1} a^{-1}]

a accumulation factor 1.86 (according to Wilke & Schaub (1986) for P) [-]

$f_{erosion}$ erosion factor considering the distance to river or lakes with an average value of 0.2 (considers only the fraction of the soil that reaches the water body, the rest is deposited in the field) [dimensionless]

A_i allocation factor for the share of agricultural inputs in the total inputs for heavy metal *i* [dimensionless]

Tab. 24: Average heavy metal contents in mg per kg soil for Switzerland (from Keller & Desaules, 2001).

Land use	Cd [mg/kg]	Cu [mg/kg]	Zn [mg/kg]	Pb [mg/kg]	Ni [mg/kg]	Cr [mg/kg]	Hg [mg/kg]
Permanent grassland	0.309	18.3	64.6	24.6	22.3	24.0	0.088
Arable land	0.24	20.1	49.6	19.5	23.0	24.1	0.073
Horticultural crops	0.307	39.2	70.1	24.9	24.8	27.0	0.077

The original values for Switzerland are used as default (Tab. 25).

The balance of all inputs into the soil (fertilisers, pesticides, seed and deposition) and outputs from the soil (exported biomass, leaching and erosion), multiplied by the allocation factor is calculated as an emission to agricultural soil.

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

If the uptake of heavy metals by plants and the emissions from leaching and erosion exceed the inputs, a negative balance will result in the agricultural soil. This happens in particular if a large biomass is harvested and the inputs are low. The heavy metals are transferred to the biomass and have to be appropriately considered when modelling the subsequent life cycle stage (i.e. returned to the soil, transferred to water via a processing, or landfilled at the end of the life).

A certain fraction of the heavy metal input into the soil stems from atmospheric deposition. The deposition would occur even without any agricultural production and is therefore not charged to the latter. An allocation factor accounts for this. The farmer is therefore responsible for a part of the inputs only (the rest stems mainly from other economic sectors), therefore only a part of the emissions is calculated in the inventory.

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

A_i allocation factor for the share of agricultural inputs in the total inputs for heavy metal i

$M_{agro\ i}$ total input of heavy metal from agricultural production in mg/(ha*year) (fertiliser + seeds + pesticides)

$M_{deposition\ i}$ total input of heavy metal from atmospheric deposition in mg/(ha*year) (Tab. 25)

In cases, where $M_{agro\ i} = 0$, i.e. no agricultural inputs to the soil occur, A_i also becomes 0.

Tab. 25: Heavy metal deposition (see Freiermuth 2006).

	Cd	Cu	Zn	Pb	Ni	Cr	Hg
Deposition [mg/ha/year]	700	2400	90400	18700	5475	3650	50

Tab. 26: Heavy-metal contents of plant material (mg/kg dry matter, from Freiermuth 2006).

Element	Cd	Cu	Zn	Pb	Ni	Cr	Hg
Unit	[mg/kg DM]						
Generic mean	0.10	6.6	32.0	0.54	1.04	0.55	0.04
Grass / Hay	0.13	8.6	40	1.2	1.68	1.09	0.15
Maize grains	0.03	2.5	21.5	0.3	1.16	0.32	0
Maize silage	0.1	5	34.5	1.61	0.48	0.7	0.01
Wheat grains	0.1	3.3	21.1	0.2	0.2	0.2	0.01
Wheat straw	0.2	2.5	9.6	0.6	0.6	0.7	NA
Barley grains	0.03	4.3	26.6	0.2	0.1	0.1	NA
Barley straw	0.1	4.8	11.1	0.6	0.8	1.2	NA
Rye straw	0.1	3.2	13	0.4	0.7	0.5	NA
Potatoes	0.04	6.45	15	0.55	0.33	0.57	0.09
Rape seed	1.6	3.3	48	5.25	2.6	0.5	0.1
Faba beans	0.04	6	30.1	0.87	1.3	0.69	0
Soya beans	0.06	15.1	47.7	0.08	5.32	0.52	0
Protein peas	0.09	10	73	0.16	0.83	0.32	0.01
Sugar beets	0.4	12	36.4	1.16	1.08	1.775	0.095
Rice grains	0.02	5.27	43.9	0.96	0.97	0.49	NA

Tab. 27: Heavy-metal contents of mineral fertilisers [mg/kg nutrient] according to Desaules & Studer (1993). No data available on Hg. Source: Freiermuth (2006).

Mineral fertilisers (%N/%P_2O_5/%K_2O/%Mg)	Cd [mg/kg nutrient]	Cu [mg/kg nutrient]	Zn [mg/kg nutrient]	Pb [mg/kg nutrient]	Ni [mg/kg nutrient]	Cr [mg/kg nutrient]
Urea (46/0/0) kg N	0.11	13.04	95.65	2.39	4.35	4.35
Calcium ammonium nitrate (20/0/0) kg N	0.25	60.00	155.00	5.50	90.00	10.00
Ammonium nitrate (27.5/0/0) kg N	0.18	25.45	181.82	6.91	47.27	14.55
Ammonium sulphate (21/0/0) kg N	0.24	19.05	142.86	5.24	8.57	9.52
Calcium ammonium nitrate (27/0/0) kg N	0.19	8.52	100.00	5.93	12.59	2.96
Magnesium ammonium nitrate (23/0/0/5) kg N	0.43	56.52	4.35	4.35	21.74	6.09
Generic mean N	0.21	22.25	121.43	5.37	17.17	7.81
Triple superphosphate (0/46/0) kg P_2O_5	113.04	97.83	650.00	7.61	95.65	567.39
Superphosphate (0/19/0) kg P_2O_5	52.63	121.05	852.63	578.95	105.26	342.11
Thomas meal (0/16/0) kg P_2O_5	1.56	250.00	425.00	75.00	125.00	12212.50
Hyperphosphate/raw phosphate (0/26/0) kg P_2O_5	50.00	115.38	915.38	23.85	76.92	611.54
Generic mean P	51.32	118.22	751.32	49.42	100.46	589.46
Potassium chloride (KCl) (0/0/60) kg K_2O	0.10	8.33	76.67	9.17	3.50	3.33
Potassium sulphate (0/0/50) kg K_2O	0.10	4.00	64.00	6.60	1.60	4.00
Raw potassium (0/0/26/5) kg K_2O	0.19	173.08	153.85	11.54	11.54	173.08
Lime kg CaO	0.12	4.00	8.00	3.60	12.20	314.00
Generic mean K	0.11	6.17	70.33	7.88	7.52	88.54

Tab. 28: Heavy-metal contents of farmyard manure and organic fertiliser (mg/kg DM, compiled by Freiermuth 2006 from from Menzi & Kessler (1998) and Desaules & Studer (1993, p. 152)). Dry matter (DM) contents from Walther *et al*. (2001, Tab. 44).

Farmyard manure	Cd	Cu	Zn	Pb	Ni	Cr	Hg	DM-content
Cattle liquid manure	0.18	37.1	162.2	3.77	4.3	3.9	0.4	9.0%
Cattle slurry	0.16	19.1	123.3	2.92	3.1	2.1	0.6	7.5%
Cattle staple manure	0.17	23.9	117.7	3.77	4.3	3.9	0.4	19.0%
Cattle manure form loose housing	0.15	22.0	91.1	2.81	4.3	3.9	0.4	21.0%
Pig liquid manure	0.21	115.3	746.5	1.76	8.6	6.7	0.8	5.0%
Pig solid manure	0.21	115.3	746.5	1.76	8.6	6.7	0.8	27.0%
Litter from broilers	0.29	43.8	349.2	2.92	40.0	10.0	0.2	65.0%
Litter from belts from laying hens	0.25	39.6	468.4	2.24	7.9	5.5	0.2	30.0%
Litter from deep pits from laying hens	0.25	39.6	468.4	2.24	7.9	5.5	0.2	45.0%

In some cases, the users want to exclude heavy metal uptake by the biomass from the total heavy metal flows. This can e.g. be the case if an incomplete life cycle is modelled. For this purpose the uptake by the crops is modelled in separate inventories (separated from the inputs). These datasets are called “product, uptake” (e.g. “wheat grains, uptake”). The heavy metal uptake is included as negative emissions into agricultural soil. A switch parameter “heavy_metal_uptake” is introduced allowing exclusion of heavy metal uptake in such situations.

3.9.10 Carbon dioxide (CO_2) emissions after urea or lime applications

After application of urea and lime, fossil CO_2 is released to the air. The worst-case approach according to IPCC (2006) is followed, so that the total amount of C is considered as released to the air is the form of CO_2.

For urea, the emission is 1.57 kg CO_2/kg Urea-N[16].

For limestone ($CaCO_3$) and dolomite ((Ca Mg)CO_3) the following emission factors apply:

- 12/100 * 44/12 = 0.44 kg CO_2/kg limestone
- 12/92.2 * 44/12 = 0.48 kg CO_2/kg dolomite.

3.9.11 Pesticide emissions

The amount of different active ingredients is determined as described in section 3.7. This section describes the modelling of the pesticide emissions in the crop inventories.

Pesticide emissions are modelled as 100% of the active substance emitted to agricultural soil[17].

Emissions resulting from field application of each of these pesticide families are modeled consistently with the pesticide inputs. For each pesticide family, a default mix of active substances are emitted to

[16] The molecular weight of urea (CH_4N_2O) is 60, the C content is 12/60, the N content is 28/60, the conversion of C into CO_2 is 44/12, from which follows: 12/60*60/28*44/12=1.57.

[17] The OLCA-Pest project (http://www.sustainability.man.dtu.dk/english/research/quantitative-sustainability-assessment1/research/research-projects/olca-pest) will publish in 2020 a refined model for pesticides emissions modelling. This may set a new baseline for future updates of the current guidelines.

the soil (100% of the applied amount is emitted), considering an even amount of each substance from the existing flow list.

3.9.12 Particulate matter ($PM_{2.5}$)

Particulate matter emissions have been demonstrated by Takai et al. (1998) in livestock buildings, where dust emission rates were measured in relation to different animal housing systems. In absence of better data, their values are used by default for the WFLDB, as interpreted into $PM_{2.5}$ by EEA (2016, chapter 3.B, tables 3.5 and A1.6) and reported in the table below.

Tab. 29: Particulate matter ($PM_{2.5}$) default emission factors for animal housing systems, far right column (expressed in kg per animal and per year). Source: EEA (2016)

Code	Livestock	EF for TSP (kg AAP^{-1} a^{-1})	EF for PM_{10} (kg AAP^{-1} a^{-1})	EF for $PM_{2.5}$ (kg AAP^{-1} a^{-1})
3B1a	Dairy cattle	1.38 ([a])	0.63 ([a])	0.41 ([a])
3B1b	Non-dairy cattle (including young cattle, beef cattle and suckling cows)	0.59 ([a])	0.27 ([a])	0.18 ([a])
3B1b	Non-dairy cattle (calves)	0.34 ([a])	0.16 ([a])	0.10 ([a])
3B2	Sheep	0.14 ([b])	0.06 ([b])	0.02 ([b])
3B3	'Swine' (Fattening pigs)	1.05([c])	0.14 ([d])	0.006 ([e])
3B3	'Swine' (Weaners)	0.27 ([c])	0.05 ([f])	0.002 ([c])
3B3	'Swine' (Sows)	0.62 ([c])	0.17 ([f])	0.01 ([c])
3B4a	Buffalo	1.45 ([a])	0.67 ([a])	0.44 ([a])
3B4d	Goats	0.14 ([b])	0.06 ([b])	0.02 ([b])
3B4e	Horses	0.48 ([g])	0.22 ([g])	0.14 ([g])
3B4f	Mules and asses	0.34 ([a])	0.16 ([a])	0.10 ([a])
3B4gi	Laying hens (laying hens and parents)	0.19 ([c])	0.04 ([h])	0.003 ([i])
3B4gii	Broilers (broilers and parents)	0.04 ([c])	0.02 ([j])	0.002 ([k])
3B4giii	Turkeys	0.11 ([l])	0.11 ([m])	0.02 ([c])
3B4giv	Other poultry (Ducks)	0.14 ([a])	0.14 ([a])	0.02 ([a])
3B4giv	Other poultry (Geese)	0.24 ([a])	0.24 ([a])	0.03 ([a])
3B4h	Other animals (Fur animals)	0.018 ([b])	0.008 ([b])	0.004 ([b])

Notes: The $PM_{2.5}$ EFs for pigs ('Swine') presented here represent the information available from the scientific literature. However, caution should be used with these EFs as the ratio between PM_{10} and $PM_{2.5}$ is considerably different from that for larger livestock categories, suggesting a particularly high degree of uncertainty with these data.

Particulate matter emissions for different agricultural crop operations are not included at this stage, as livestock emissions appeared to be negligible, but they might be included based on EEA 2016, chapter D, tables 3.7 and 3.8.

3.10 Carbon uptake by plants

Carbon is taken up in the form of carbon dioxide and fixed in the biomass. The carbon dioxide uptake by the growing crops is considered a resource input, which is important for the assessment of the climate change impact.

The WFLDB provides the inventory of carbon uptake and release by plants but does not characterize them. Most LCIA methods apply a biogenic carbon neutral approach, hence will ignore uptake and release. However, some methods consider uptake (factor -1) and consequently the emissions (factor 1). LCA practitioners must take care to ensure approach consistency across all life cycle stages.

The CO_2 uptake by the plant is estimated by multiplying the carbon content in the plant dry matter by the stoichiometric factor 44/12.

The carbon content of the plants or the products can be calculated from the lignin, cellulose, carbohydrate, protein, fat, fibre, and ash composition of the harvested products and their respective carbon contents, reported in Tab. 31.

Data on the composition of different products can be found e.g. in the USDA National Nutrient Database (http://ndb.nal.usda.gov/), in the Animal Feed Resources Information System provided by INRA CIRAD AFZ and FAO, called Feedipedia (http://www.feedipedia.org/) or in the Swiss feed database (www.feedbase.ch). If no composition information is available, 47.5% is taken as default value for carbon content of dry mass (http://www.fao.org/forestry/17111/en/). If other sources than the above-mentioned are used, this will be described in the dataset-specific documentation. Carbon bound in crop residues that remain on the field is not considered as residues are decomposed and carbon is thus released.

The net release of biogenic CO_2 from biomass is included as 'Carbon dioxide, biogenic'. Only net changes of biomass stocks are considered, i.e. if the C stock in the biomass changes between the beginning and the end of the inventory period (typically a growing season).

Tab. 30: Carbon contents of different fractions of the biomass

Fraction	C-content (g/kg dry mass)	Source
Lignin	645	Ma et al. (2018)
Cellulose and hemicellulose	440	Ma et al. (2018)
Carbohydrates and NSC	440	Rouwenhorst et al. (1991)
Proteins	530	Rouwenhorst et al. (1991)
Lipids	750	Nemecek & Kägi (2007)
Fibres	440	Nemecek & Kägi (2007)
Ash	0	Nemecek & Kägi (2007)

NSC: non-structural carbohydrates

3.11 Crop production activities

3.11.1 Machinery for field operations

If no level 4 or level 3 data are available, the following principles for generic data of level 1 and level 2 are applied:

Level 1 data for machinery use of field operations

Relates to data about the total machinery input per hectare for a specific crop and country but not referring to specific field activities. As background dataset, the ecoinvent process "Agricultural machinery, general (kg)" is used. The machinery input is estimated according to the MEXALCA approach (Nemecek *et al.* 2012; Roches *et al.* 2010) by using the machinery input according to the intensity index for machinery use in a given country (based on FAOSTAT data). In addition, for application of fertilisers, pesticides and for irrigation the machinery use is related to the yield of a specific crop, based on the assumption that higher yield is associated with higher machinery input. In contrast, soil cultivation, sowing and harvesting are assumed to be non-correlated to the yield.

Level 2 data for machinery use of field operations

Such data are specific to field operations (e.g. soil cultivation, sowing, application of fertiliser and pesticide, harvesting). Here also, the MEXALCA approach (Nemecek *et al.* 2012; Roches *et al.* 2010) is applied. In order to consider the increase for soil cultivation with increased portion of clay in the soil, the Cranfield model (Williams *et al.* 2006) is applied. The Cranfield model can be applied for cereals, soya, maize (grain and forage) and field beans under agronomic and economic conditions similar to England. Soil conditions for other countries are taken from the SQCB tool (Faist Emmenegger *et al.* 2009). The portion of no-till for each country is estimated according to Derpsch and Friedrich (2009).

Machinery types (non exhaustive list):

Soil cultivation

- Soil tillage, plough (ha)
- Soil tillage, chisel (ha)
- Soil tillage, spring-tine weeder (ha)
- Soil tillage, rotary harrow (ha)
- Soil tillage, spring-tine harrow (ha)
- Soil tillage, hoeing and earthing up, potatoes (ha)
- Soil tillage, roll (ha)
- Soil tillage, rotary cultivator (ha)

Sowing, planting

- Sowing (ha)
- Planting (ha)
- Potato planting (ha)

Fertilisation

- Fertilizing, by broadcaster (ha)

Plant protection

- Application of pesticides, by field sprayer (ha)

Harvesting

- Combine harvesting (ha)
- Chopping maize (ha)
- Fodder loading by self-loading trailer (m3)
- Harvesting beets by complete harvester (ha)
- Harvesting potatoes by complete harvester (ha)
- Haying by rotary tedder (ha)
- Loading bales (unit)
- Mowing by motor mower (ha)
- Mowing by rotary mower (ha)
- Potato grading (kg)
- Potato haulm cutting (ha)
- Swath by rotary windrower (ha)

Irrigation facility

- Surface irrigation, with gravity irrigation and flood irrigation being special cases of surface irrigation.
- Sprinkler irrigation, or spray irrigation

- Drip irrigation, or micro-irrigation

The ecoinvent database provides infrastructure data for sprinkler irrigation. This includes a mobile sprinkler system; with fix installed pump, 100 m water pipe and hydrant, turbine propulsion, 300 m water hose, automaton, shed, excavation (100 m^3 soil/ha) and tractor operation (with diesel consumption of 3.78 kg/ha) (Nemecek and Kägi 2007).

For surface irrigation, the ecoinvent sprinkler irrigation infrastructure is adapted as follows:

- Tractor operation is doubled
- Excavation is doubled
- Diesel use for tractor operation and excavation is doubled
- Water hoses are removed

For drip irrigation, data from Torrellas et al. (2012) are used.

3.11.2 Drying

Level 1 data for drying inputs

The MEXALCA approach (Nemecek *et al.* 2012; Roches *et al.* 2010) is used to estimate the inputs for grain and forage drying. This model considers that drying is proportional to the yield (crop-specific) and the drying indices (country-specific).

Level 2 data for drying inputs

Level 2 data are based on country-specific literature for specific crops, when available. Substantial differences to level 1 data shall be documented and explained.

3.12 Animal production activities

Included process for animal fattening systems at farm:

- Young animal purchase for fattening or milking
- Stable (including infrastructure)
- Direct emissions from animals and manure storage to air
- Not included: Emission from manure spreading, because these are part of crop and feed production processes
- Feed (roughage, concentrate feed, pasture)
- Feed storage facility
- Transport (mainly for feed from storehouse to the farm)
- Water
- Energy carriers and machinery used for husbandry

Fattening systems for cattle, swine and chicken at farm:

Only intensive, non-grazing production systems are modelled based on concentrated feed. Typical for intensive systems is a relative short fattening period and relative low total feed consumption compared to less intensive systems or grazing systems.

Critical parameters for animal production are the intensity of the production and the organisation of the system, feeding, housing, manure management, and the proportion of grazing.

The intensity of the system can be described by the milk yield per cow and per year for dairy systems. For meat production, the daily body weight gain is a key parameter, which can be calculated from the initial and final weights, as well as the duration of fattening/growth. For milk and meat production the feed conversion ratio, i.e. the amount of feed consumed per kg of milk or meat, is a good indicator to roughly assess the environmental impacts of the production.

For beef production, two different systems are distinguished: 1) suckler cow systems and 2) combined dairy and beef production. In suckler cow systems, the calf consumes all the milk and therefore all impacts of the suckler cows are allocated to the beef production. In combined dairy and beef production, both milk and beef are produced and therefore an allocation between these two products is applied.

For milk production, the following parameters are used to define typical production systems:

- Herd size (large, medium, small, micro)
- Grazing vs. non-grazing
- Mechanised vs. non-mechanised

For eggs production one intensive system is defined where laying hens are kept in barn, single tiered but not in battery cage.

3.12.1 Animal feed production

In general, feedstuffs represent a major share of the environmental impacts of animal production systems. The number of different feedstuffs used can be considerable as well as their sourcing. Therefore, a number of feed basket archetypes have been created to improve modelling consistency across animal types, countries and housing systems.

For the modelling, the following priorities have been applied:

1. When the requested feedstuff inventory is available for the investigated country, it shall be used.
2. When the requested feedstuff inventory is available for another country or higher geographical area, the country with most similar conditions shall be chosen.
3. When requested feedstuff inventory is not available, a feedstuff with a similar production route (e.g. rapeseed meal for sunflower meal) or with similar function (energy rich feed, protein rich feed) shall be modelled.
4. If a feedstuff represents more than 30% of the total ration and no satisfactory data are available, a specific inventory shall be created, if possible.

The feed modelling overview is presented in Figure 8. This framework enables the creation of feed mixture archetypes and feed basket archetypes for any given animal in any given country, in any type of housing system (e.g.: intensive production farm). Default feed basket archetypes (Figure 9) are proposed based on the LEAP reports[18] and can be refined in any case if data are available.

Each of the components of the feed basket is built from WFLDB crop datasets and includes the relevant transformation processes. Default components of the basket (e.g.: high protein compound feed mix)

[18] FAO (2016a, 2016b, 2016c, 2016d and 2018).

are regionalised at the continental level and proposed according to Alig (2009) and further literature review, complemented with assumptions taking into account regional production and importation.

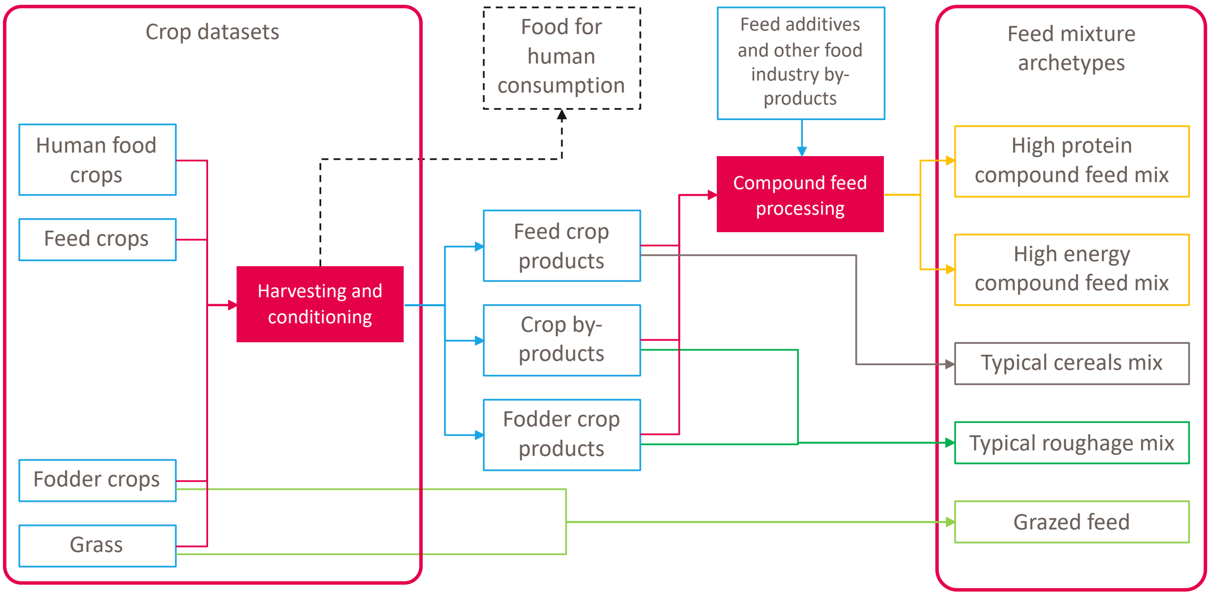

Figure 8: Feed modelling overview, from crop datasets to feed mixture archetypes.

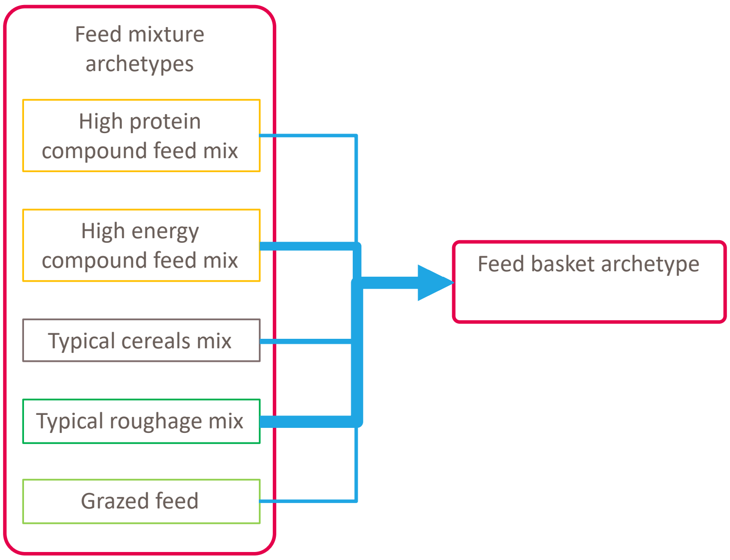

Figure 9: Constitution of a feed basket archetype, built from feed mixture archetypes based on the LEAP reports. The width of the arrows illustrates the relative contribution from each feed mix.

Where detailed data on feeding are lacking, the total energy intake in feed can be estimated by the methodology described by IPCC (2006) vol. 4, chap. 10.

3.12.2 Housing, manure management and grazing

In addition to feeding, the housing and manure management systems as well as the proportion of feed taken up on pastures are critical parameters. Ideally, data representative of the region of the modelled system should be used. Where such information is not available, the most frequent ("typical") system shall be modelled.

For animal systems, six different manure management systems are considered:

- Daily spread
- Dry lot
- Lagoon
- Liquid/Slurry
- Pit storage
- Solid storage

Manure dropped in pasture is considered in the pasture datasets, not as a manure management. Manure burning as fuel is associated to dry lot for the drying stage. The combustion impacts are not accounted for, as they are attributed to the function using the manure as fuel.

The shares of manure management systems in different countries are taken from IPCC (2019), Tables 10A6 and following. This is the only exception where IPCC 2019 is used, since these data were not completely available in the previous version.

Emission factors from IPCC (2006) are used for three average climate conditions:

- Cool (<15°C)
- Temperate (15 to 25°C)
- Warm (>25°C)

Emissions that are accounted for:

- To air: CH_4, NH_3, N_2O (direct and indirect) and NOx
- To groundwater: NO_3^-

The manure emission models are described, per substance, in section 3.9: Direct emissions from crop and animal production.

3.12.3 Slaughtering

Included process at slaughterhouse:

- Transport of animal from farm to slaughterhouse (200 km assumed)
- Slaughterhouse
  - energy carriers
  - tap water
  - packaging film
  - chemicals: acid and alkaline foam cleaning agents, and disinfectant
  - slaughterhouse and infrastructure
  - Waste treatment (e.g. sewage, disposal bio-waste)
- Multi-output dataset: several co-products from slaughtering considered; economic allocation is applied (see section 2.6.4)

3.13 Food transformation activities

3.13.1 Food processing

Several food processing activities are modelled in the WFLDB, including:

- Dairy products manufacturing
- Oil extractions
- Coffee processing
- Cocoa processing and chocolate manufacturing

- Bread and pasta manufacturing
- Margarine production
- Tomato processing

Data for such activities are taken from the literature (empirical studies or technical data) and crosschecked by sectorial experts whenever possible. They are either representative of average global practices or specific to a given country. The data source, technology and calculations are provided in the documentation of each dataset.

3.13.2 Home cooking

Major variations in home cooking practices are observed among individuals and cultures. The datasets developed within the WFLDB cannot aim to cover all possible cooking modes but focus on those most commonly seen in western countries: baking, frying, boiling, steaming and microwaving.

For frying, boiling and (unpressurized) steaming, different energy sources for stoves are assessed: electricity, natural gas and liquefied petroleum gas (LPG). Datasets include parameters in such a way that cooking time, microwave power and volume of boiling water can be customized.

Modelling is based equations from Sonesson (2003) and Milà i Canals *et al.* (2008), as well as technical data on cooking appliances.

3.14 Electricity

The national consumption electricity mix (including imports) is used for national datasets. Ecoinvent v3 data are used to model electricity production and transmission. When not available, data from the International Energy Agency is used (IEA 2011) to create specific national production mixes and electricity at grid (high, medium and low voltage) datasets.

3.15 Infrastructure

Agricultural infrastructure and equipment are allocated to the production datasets according to Nemecek & Kägi (2007). The general rule is:

$I_p = I_{tot}/PV_{tot}$

I_p = amount of infrastructure/equipment allocated to one unit of product p.

I_{tot} = total amount of infrastructure/equipment

PV_{tot} = total production of product p over the lifetime of infrastructure/equipment I.

3.16 End-of-life activities

3.16.1 Waste treatment

As typical *cradle-to-gate* or *gate-to-gate* datasets, the end of life of the products themselves modelled in the WFLDB is not addressed. The so-called *cut-off* allocation approach is applied to waste generated in the different production or transformation activities, in a way that is consistent with ecoinvent.

Final treatment – landfilling or incineration – of waste is allocated to the product system. Waste fractions that are reused in a different product system or that are recycled into new marketable materials are fully allocated to other product systems. These flows are therefore modelled in the inventory, but no treatment activity is accounted for.

The *cut-off* approach makes it easy for users to adapt the datasets with a different end-of-life allocation rule, such as the Circular Footprint Formula (CFF) proposed by the PEF initiative. WFLDB datasets published through the ecoinvent database may also have different allocation rules for waste flows (e.g. allocation at the point of substitution).

The end-of-life of packaging materials, auxiliary materials and infrastructure that are not converted to the modelled product are included.

3.16.2 Wastewater treatment

Wastewater treatment plants (WWTP) in ecoinvent are classified in five capacity classes. WWTP capacities are expressed in per-capita equivalents [PCE]. Class 1 is the largest infrastructure (over 100000 PCE/year) while class 5 is the smallest (30-2000 PCE/year) (Doka 2007).

When the activity takes place in a rural area, class 4 (2000-10000 PCE/year) is used by default. When the activity takes place in an urban area, class 2 (50000-100000 PCE/year) is used by default.

In situations where it can be reasonably assumed that no WWT facility is available, water outflows are considered released in the environment. Known and quantified pollutants are accounted for as emissions to surface water.

4 Data quality

4.1 Dataset documentation

The documentation structure is consistent with requirements of ecoinvent version 3.5 (Weidema *et al.* 2013), which distinguishes between specific information inherent to a given dataset and information valid for several datasets documented in a separate document (Bengoa et al. 2020).

4.2 Data quality assessment

Two levels of data quality assessment are assessed.

4.2.1 Data quality at dataset level

The European Commission Product Environmental Footprint (PEF) data quality assessment is applied. According to the PEF Guide (EU-JRC 2010a; p.329) the following six criteria for quality assessment of LCI data shall be used:

1. Technological representativeness (TeR)
2. Geographical representativeness (GR)
3. Time-related representativeness (TiR)
4. Completeness (C)
5. Precision / uncertainty (P)
6. Methodological appropriateness and consistency (M).

Each criterion is rated on the scale presented in Tab. 31:

Tab. 31: ILCD data quality rating scale (EU-JRC 2010a; p. 331)

Rating	Definition
1	Very good
2	Good
3	Fair
4	Poor
5	Very poor
Additional options, not being quality levels	
5	Not evaluated or unknown
0	Not applicable

The overall data quality rating (DQR) is calculated by summing up the achieved quality rating for each of the quality criteria, divided by the total number of criteria, i.e. the arithmetic mean. The calculated DQR is then qualified as:

- Excellent quality: $DQR \leq 1.6$
- Very good quality: $1.6 < DQR \leq 2.0$

- Good quality: $2.0 < DQR \leq 3.0$
- Fair quality: $3.0 < DQR \leq 4.0$
- Poor quality: $DQR > 4.0$

4.2.2 Data quality at flow level

At flow level the quality is expressed as the uncertainty related to its amount, which enables to conduct Monte Carlo simulation. To estimate the uncertainty the "ecoinvent pedigree approach" as defined by Weidema *et al.* (2013; pp. 70-77) is applied. The flow uncertainty is calculated from the "basic uncertainty" and the estimated variance of the "underlying normal distribution".

The underlying normal distribution is characterised by a standard deviation calculated based on the 5 quality scores from the "pedigree matrix". This matrix lists 5 indicators, i.e. reliability, completeness, temporal correlation, geographical correlation, and further technological correlation, as detailed in Tab. 32**.**

Tab. 32: Pedigree matrix used to define indicator scores for data categories (Weidema *et al.* 2013; p. 76)

Score	1	2	3	4	5 (default)
Reliability	Verified data based un measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimates (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<50%) relevant for the market considered OR >50% of the sites but from shorter periods	Representative data from only one site relevant for the market considered OR some sites but from shorter periods	Representativeness unknown or data from a small number of sites AND from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown OR more than 15 years difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown OR distinctly different area (e.g. Europe instead of North-America)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (e.g. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale OR from different technology

To ensure consistency throughout the database and to keep the workload for estimating the uncertainties in a feasible range, the default scores for data categories are predefined as described in Tab. 33.

Tab. 33: Assumed default scores per data category for pedigree matrix indicators

Data category	Indicator scores						"Comment field" of the process
	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Sample size	
Seed quantity	2	1	1	1	1	na	(2,1,1,1,1,na)
Fertiliser quantity and fertiliser application	2	1	1	1	1	na	(2,1,1,1,1,na)
Pesticide quantity and pesticide application	2	2	1	1	1	na	(2,2,1,1,1,na)
Other machinery usage, grain drying, land use	2	1	1	1	1	na	(2,1,1,1,1,na)
Transports	4	1	1	1	1	na	(4,1,1,1,1,na)
Direct field emissions	2	2	1	1	1	na	(2,2,1,1,1,na)
Irrigation water	2	1	1	1	1	na	(2,1,1,1,1,na)

4.3 Quality control procedure

The quality control procedure described below applies to all datasets developed within the WFLDB:

1. Technical control – focus on calculations: a technical expert of Quantis verifies that calculations and assumptions are correct and aligned with the WLFDB modelling guidelines.
2. Technical control – focus on modelling choices: a technical expert from Quantis verifies which elementary flows and background datasets were used, checks their relevance and consistency among datasets.
3. Metadata control: a technical expert from Quantis verifies that datasets are fully documented and that all metadata are properly recorded.
4. External quality control: a scientific expert of Agroscope controls that datasets are consistently modelled, are aligned with the WFLDB guidelines, and fulfil overall quality standards of the WFLDB.
5. Third-party review: a panel of third party experts in LCA of agro-food verifies that the Guidelines are accurate and comprehensive.

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6 Appendices

6.1 World irrigation statistics

Tab. 34: Sprinkler and micro irrigated area (ICID 2012)

Country	Total irrigated area [Mha]	Sprinkler irrigation [ha]	Micro irrigation [ha]	Percentage sprinkler irrigation of total irrigated area [%]	Percentage micro irrigation of total irrigated area [%]	Year of reporting
India	60.9	3044940	1897280	5%	3%	2010
China	59.3	2926710	1669270	5%	3%	2009
United States	24.7	12348178	1639676	50%	7%	2009
Iran	8.7	460000	270000	5%	3%	2009
Mexico	6.2	400000	200000	6%	3%	1999
Turkey	5.34	500000	150000	9%	3%	2012
Russia	4.5	2500000	47000	56%	1%	2008
Brazil	4.45	2413008	327866	54%	7%	2006
Uzbekistan	4.223	4300000	2000	102%	0%	2009
Spain	3.47	782508	1658317	23%	48%	2011
Egypt	3.42	450000	104000	13%	3%	2000
France	2.9	1379800	103300	48%	4%	2011
Italy	2.67	981163	570568	37%	21%	2010
Australia	2.545	524480	190720	21%	7%	2000
Japan	2.5	430000	60000	17%	2%	2010
Ukraine	2.18	2450000	52000	112%	2%	2010
Kazakhstan	2.13	1400000	17000	66%	1%	2006
South Africa	1.67	920059	365342	55%	22%	2012
Morocco	1.65	189750	8250	12%	1%	2003
Saudi Arabia	1.62	716000	198000	44%	12%	2004
Philippines	1.52	7175	6635	0%	0%	2004
Romania	1.5	448000	4000	30%	0%	2008
Azerbaijan	1.433	610000	100	43%	0%	2009
Syria	1.28	93000	62000	7%	5%	2000
Chile	1.09	16000	23000	1%	2%	2006
Korea	1.01	200000	400000	20%	40%	2009
Canada	0.87	683029	6034	79%	1%	2004
Portugal	0.63	40000	25000	6%	4%	1999
Bulgaria	0.588	21000	3000	4%	1%	2008
Germany	0.54	525000	5000	97%	1%	2005
Chinese Taipei	0.38	18850	8750	5%	2%	2009
Malaysia	0.38	2000	5000	1%	1%	2009
Slovak Republic	0.313	310000	2650	99%	1%	2000
Israel	0.231	60000	170000	26%	74%	2000
Moldova	0.228	145000	15000	64%	7%	2009
Hungary	0.22	185000	7000	84%	3%	2008

Country	Total irrigated area [Mha]	Sprinkler irrigation [ha]	Micro irrigation [ha]	Percentage sprinkler irrigation of total irrigated area [%]	Percentage micro irrigation of total irrigated area [%]	Year of reporting
Czech Republic	0.153	11000	5000	7%	3%	2007
Great Britain	0.11	105000	6000	95%	5%	2005
Poland	0.1	5000	8000	5%	8%	2008
Finland	0.07	60000	10000	86%	14%	2010
Malawi	0.055	43193	5450	79%	10%	2000
Macedonia	0.055	5000	1000	9%	2%	2008
Slovenia	0.0073	8072	733	111%	10%	2009
Lithuania	0.0044	4463	-	101%	0%	2010
Estonia	0.001	500	500	50%	50%	2010

Tab. 35: Relative areas irrigated with ground water, surface water and non-conventional sources (Siebert *et al.* 2010)

Country	Ground water	Surface water	Non-Conventional sources
Global	39%	61%	0%
Afghanistan	16%	84%	0%
Albania	1%	99%	0%
Algeria	64%	34%	2%
Andorra	25%	75%	0%
Angola	20%	80%	0%
Antigua and Barbuda	15%	85%	0%
Argentina	24%	76%	0%
Armenia	19%	81%	0%
Australia	21%	77%	2%
Austria	83%	17%	0%
Azerbaijan	7%	93%	0%
Bahrain	90%	0%	10%
Bangladesh	74%	26%	0%
Barbados	90%	10%	0%
Belarus	15%	85%	0%
Belgium	58%	42%	0%
Belize	22%	78%	0%
Benin	18%	82%	0%
Bhutan	0%	100%	0%
Bolivia	7%	93%	0%
Bosnia and Herzegovina	30%	70%	0%
Botswana	46%	54%	0%
Brazil	19%	81%	0%

Country	Ground water	Surface water	Non-Conventional sources
Brunei Darussalam	0%	100%	0%
Bulgaria	23%	77%	0%
Burkina Faso	12%	88%	0%
Burundi	0%	100%	0%
Cambodia	0%	100%	0%
Cameroon	4%	96%	0%
Canada	9%	91%	0%
Cape Verde	14%	86%	0%
Central African Republic	0%	100%	0%
Chad	20%	80%	0%
Chile	5%	95%	0%
China	30%	70%	0%
Colombia	5%	95%	0%
Comoros	4%	96%	0%
Congo	0%	100%	0%
Costa Rica	17%	83%	0%
Cote D'ivoire	0%	100%	0%
Croatia	37%	63%	0%
Cuba	45%	55%	0%
Cyprus	60%	39%	1%
Czech Republic	7%	93%	0%
Korea, Democratic People's Republic of	14%	86%	0%
Zaire	0%	100%	0%
Denmark	100%	0%	0%
Djibouti	100%	0%	0%
Dominican Republic	22%	78%	0%
Ecuador	12%	88%	0%
Egypt	10%	90%	0%
El Salvador	7%	93%	0%
Eritrea	24%	76%	0%
Estonia	0%	100%	0%
Ethiopia	1%	99%	0%
Fiji	10%	90%	0%
Finland	15%	85%	0%
France	45%	55%	0%
French Guiana	5%	95%	0%
Gabon	0%	100%	0%
Gambia	1%	99%	0%
Georgia	0%	100%	0%
Germany	79%	21%	0%
Ghana	21%	76%	2%
Greece	48%	52%	0%

Country	Ground water	Surface water	Non-Conventional sources
Grenada	0%	100%	0%
Guadeloupe	10%	90%	0%
Guam	80%	20%	0%
Guatemala	22%	78%	0%
Guinea	0%	100%	0%
Guinea-bissau	22%	78%	0%
Guyana	0%	100%	0%
Haiti	15%	85%	0%
Honduras	8%	92%	0%
Hungary	22%	78%	0%
India	63%	37%	0%
Indonesia	1%	99%	0%
Iran	62%	38%	0%
Iraq	6%	94%	0%
Ireland	20%	80%	0%
Israel	49%	33%	18%
Italy	33%	67%	0%
Jamaica	90%	10%	0%
Japan	9%	91%	0%
Jordan	53%	47%	0%
Kazakhstan	5%	94%	1%
Kenya	1%	99%	0%
Kuwait	61%	0%	39%
Kyrgyzstan	1%	99%	0%
Lao People's Democratic Republic	0%	100%	0%
Lebanon	52%	48%	0%
Lesotho	75%	25%	0%
Liberia	1%	100%	0%
Libyan Arab Jamahiriya	99%	1%	1%
Lithuania	74%	26%	0%
Luxembourg	70%	30%	0%
Madagascar	0%	100%	0%
Malawi	0%	100%	0%
Malaysia	8%	92%	0%
Mali	0%	100%	0%
Malta	99%	1%	0%
Martinique	5%	95%	0%
Mauritania	11%	89%	0%
Mauritius	25%	75%	0%
Mexico	39%	61%	0%
Mongolia	36%	64%	0%
Montenegro	100%	0%	0%

Country	Ground water	Surface water	Non-Conventional sources
Morocco	46%	54%	0%
Mozambique	1%	99%	0%
Myanmar	5%	95%	0%
Namibia	22%	78%	0%
Nepal	20%	80%	0%
Netherlands	58%	42%	0%
New Zealand	31%	69%	0%
Nicaragua	70%	30%	0%
Niger	2%	98%	0%
Nigeria	29%	71%	0%
Northern Mariana Islands	79%	21%	0%
Norway	6%	94%	0%
Palestinian Territory	100%	0%	0%
Oman	100%	0%	0%
Pakistan	36%	64%	0%
Panama	4%	96%	0%
Paraguay	10%	90%	0%
Peru	28%	72%	0%
Philippines	14%	86%	0%
Poland	10%	90%	0%
Portugal	55%	45%	0%
Puerto Rico	87%	13%	0%
Qatar	93%	0%	7%
Korea, Republic Of	6%	94%	0%
Moldova	0%	100%	0%
Reunion	22%	78%	0%
Romania	9%	91%	0%
Russian Federation	36%	64%	0%
Rwanda	1%	99%	0%
Saint Kitts and Nevis	50%	50%	0%
Saint Lucia	0%	100%	0%
Sao Tome and Principe	0%	100%	0%
Saudi Arabia	97%	0%	3%
Senegal	10%	90%	0%
Serbia	14%	86%	0%
Seychelles	0%	100%	0%
Sierra Leone	1%	99%	0%
Slovakia	8%	92%	0%
Slovenia	11%	89%	0%
Somalia	15%	85%	0%
South Africa	9%	92%	0%
Spain	37%	63%	0%

Country	Ground water	Surface water	Non-Conventional sources
Sri Lanka	1%	99%	0%
Sudan	4%	96%	0%
Suriname	0%	100%	0%
Swaziland	2%	98%	0%
Sweden	34%	66%	0%
Switzerland	22%	78%	0%
Syrian Arab Republic	68%	32%	0%
Tajikistan	9%	87%	3%
Thailand	9%	91%	0%
Macedonia	6%	94%	0%
Timor-leste	2%	98%	0%
Togo	1%	99%	0%
Trinidad and Tobago	10%	90%	0%
Tunisia	59%	39%	2%
Turkey	49%	51%	0%
Turkmenistan	3%	98%	0%
Uganda	1%	99%	0%
Ukraine	0%	100%	0%
United Arab Emirates	100%	0%	0%
United Kingdom	40%	60%	0%
Tanzania	9%	91%	0%
United States of America	60%	40%	0%
Virgin Islands, U.S.	89%	11%	0%
Uruguay	8%	92%	0%
Uzbekistan	6%	94%	0%
Venezuela	2%	98%	0%
Vietnam	1%	99%	0%
Yemen	66%	32%	2%
Zambia	4%	96%	0%
Zimbabwe	12%	88%	0%

6.2 Degrees of detail for crop production inputs

Tab. 36: Degrees of detail for crop-related production inputs

Input category	**Low detail** (level 1 data)	**Medium detail** (level 2 and 3 data)	**High detail** (level 4 data)
Fertilisers	Amount per nutrient N, P, and K	**Types of mineral fertiliser :** • N-fertiliser • P-fertiliser • K-fertiliser **Types of organic fertiliser:** • manure (if possible separate amount for solid and liquid manure) • compost and other organic fertiliser • sewage sludge	**N-fertiliser type (mineral)** N ammonium nitrate (kg N) N urea (kg N) N urea-AN (kg N) N mono-ammonium phosphate (MAP, kg N) N di-ammonium phosphate (DAP, kg N) N an-phosphate (kg N) N lime-ammonium nitrate (kg N) N ammonium sulphate (kg N) N potassium nitrate (kg N) N ammonia liquid (kg N) **P-fertiliser type (mineral)** P triple-superphos. (kg P2O5) P superphosphate (kg P2O5) P mono-ammonium phosphate (MAP, kg P2O5) P di-ammonium phosphate (DAP, kg P2O5) P AN-phosphate (kg P2O5) P hyperphosphate (raw phosphate, kg P2O5) P Thomas phosphate (kg P2O5) **K-fertiliser type (mineral)** K potassium salt (KCl, kg K2O) K potassium sulphate (K2SO4, kg K2O) K potassium nitrat (kg K2O) K patentkali (kg K2O) **Manure** Share of animal species (cattle, pigs, poultry, solid and liquid manure distinguished)
Pesticides	The total amount of active ingredients (A.I.) used per hectare	Amount of input per pesticide group: • herbicide • insecticide • fungicide	Amount of specific A.I. per pesticide group. In SALCA there are about 100 A.I. per pesticide group.

Input category	**Low detail** (level 1 data)	**Medium detail** (level 2 and 3 data)	**High detail** (level 4 data)
Machinery	Total hours of machinery	Total hours per work process: • Soil cultivation • Sowing, planting • Harvesting	**Machinery type per work process (hours):** **Soil cultivation** • Soil tillage, plough (ha) • Soil tillage, chisel (ha) • Soil tillage, spring-tine weeder (ha) • Soil tillage, rotary harrow (ha) • Soil tillage, spring-tine harrow (ha) • Soil tillage, hoeing and earthing up, potatoes (ha) • Soil tillage, roll (ha) • Soil tillage, rotary cultivator (ha) **Sowing, planting** • Sowing (ha) • Planting (ha) • Planting potatoes (ha) **Fertilisation** • Fertilizing, with broadcaster (ha) **Plant protection** • Application of plant protection products, with ground crop sprayer (ha) **Harvesting** • Threshing with combine harvester (ha) • Chopping maize (ha) • Picking-up the forage with self-propelled loader (m3) • Harvesting beets with complete harvester (ha) • Harvesting potatoes with complete harvester (ha) • Haying with rotary tedder (ha) • Loading bales (unit) • Mowing with motor mower (ha) • Mowing with rotary mower (ha) • Grading potatoes (kg) • Removing potato haulms (ha) • Windrowing with rotary swather (ha)
Irrigation	Total water (m3) used for irrigation Total diesel or electricity used for pumping (MJ)	Water use per irrigation type: • Sprinkler (diesel; electricity) • Drip (diesel; electricity) • Surface (diesel; electricity)	Irrigation type x Water type, whereas water types are: • Groundwater (m3) • Surface water (m3) • Rain water (m3) • Length of irrigation pipes and hoses if available