Global Metrics for Sustainable Feed

GFLI methodology and project guidelines

28 October 2020

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Definitions

GFLI-Database	All datasets that are available by GLFI
Database	A subset of datasets within the context of the GFLI database
Dataset	data of a feed ingredients regarding its environmental impact or data needed to calculate its environmental impact
Feed ingredients	Ingredients for feed for food producing animals that are plant or animal based or from other sources (minerals, chemicals)
Life Cycle Assessment (LCA)	Methodology for assessing environmental impacts associated with all the stages of the lifecycle of a commercial product, process, or service
LCA dataset	Life Cycle Impact Assessment (LCIA) data of a feed ingredient
LCI dataset	Life Cycle Inventory (LCI) data of a feed ingredient
Inventory data	Data of emissions and resource use
Primary production	Farm practices related to cultivation of crops and/ or animal husbandry yielding milk, meat or eggs
Sector(al) data	LCI/A data of feed ingredients representative for a certain sector. They are developed using primary data collected from a representative sample of companies of that sector
Regional data	LCI/A data representative for a certain region collected from secondary data
Default data	LCI/A data from the Agri-footprint database which uses the PEF modelling rules for agriculture and is also the basis for the EC feed database
Branded data	LCI/A data for a feed ingredient marketed under a certain brand, owned by a company or other entity such as scheme owners, farm collectives etc.
Product Environmental Footprint (PEF)	Set of rules on how to measure the life cycle environmental performance of the product in scope
PEFCR Feed	product environmental footprint category rules for feed of food producing animals

1 Introduction

1.1 Context

This guidance-document shall be used by parties that want to generate or update a Global Feed LCA Institute (GFLI) dataset for a feed ingredient or a group of feed ingredients in the current database. It can be used for developing a regional, sectoral, or branded dataset or to improve or expand datasets and/or methodology.

This document was initially drafted during and after the development of the European Union (EU), Canada, and US GFLI databases in 2016 and 2017. A first version, derived in 2016, was used by the Canadian and US projects when developing their databases. This earlier version was much more concise and merely focused on the procedure of selecting the set of feed ingredients, defining regional granularity, and identifying sources to be used for deriving datasets. The specific LCA methodology that needs to be used for modelling the inventory flows of datasets was also briefly explained referring to several documents. However, essential parts of the reference documents were still under construction, such as the Product Environmental Footprint Category Rules (PEFCR), or had not been developed yet, such as the methodology document for the EC feed database.

During the data collection process with US and Canada, it became clear that a much more detailed document is needed that entails all the necessary information on data collection and LCI methodology. Now that the EC methodology pilot (PEF and database) has been finalized and with the experience of the US and Canada project, the first complete guidance on collecting data and maintaining data and methodology for the GFLI database has been published.

This document is a living document that is intended to be updated regularly.

1.2 Set-up of the document

- Chapter 2: gives a brief introduction of the GFLI
- Chapter 3: describes the methodology for collecting GFLI compliant datasets

This document is published together with the GFLI procedures document.

1.3 Authors and review team

This document is drafted by Hans Blonk, Roline Broekema and Mike van Paassen under supervision of the GFLI Technical Management Committee (TMC) consisting, during the development of this document, of:
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1.4 Version and validity

Version no:	1.1
Publication:	November 2020
Valid until:	next update

1.5 Pilot on branded data

A pilot testing the requirements for GFLI branded data is ongoing. The current requirements set on branded data are being tested. As a result of the pilot the requirements can change, and they will become definitive after implementation of the results of the pilot on branded data.

2 The Global Feed LCA Institute (GFLI)

2.1 Goal of the institute

The Global Feed LCA Institute (GFLI) is an independent animal nutrition and food industry institute with the purpose of developing a publicly available Feed Ingredients Life Cycle Analysis (LCA) database to support meaningful environmental assessment of animal nutrition products and stimulate continuous improvement of the environmental performance in the animal nutrition, animal production and food industry. GFLI will maintain and expand its regional and sectoral Animal Nutrition LCA database, ensuring the integrity and quality of the LCA ingredient datasets in accordance with the Food and Agriculture Organization of the United Nations Livestock Environmental Assessment and Performance Partnership (FAO/LEAP) guidelines for animal nutrition and food chain systems. The Institute will provide public access to the GFLI database, as the recognized global reference for feed ingredients LCA data by the public and private sector (LCA researchers, industry, academia and government bodies). The institute will also facilitate GFLI database access for stakeholders in the field of animal nutrition, animal production and food industry, for use in conducting environmental footprint calculations of their products and meaningful comparisons based on a harmonized methodology.

2.1.1 GFLI governance mechanism

The executive body of the GFLI is the GFLI Board of Directors, composed of representatives of the GFLI members and the (non-voting) Technical Management Committee (TMC) Chair. The GFLI Board of Directors oversees all activities of the database development projects and is supported by the TMC. The TMC advices the Board on multiple technical and methodological aspects. The TMC is made up of experts nominated by GFLI Members. The mandate of the TMC is to act as the gatekeeper of the GFLI Methodology and Procedures guidance documents and to guide the expansion and improvement of the database.

To improve objectivity and to strengthen its connection with value chain partners, a Scientific Advisory Council (SAC) will be developed. The group of LCA (non-feed related) experts, will advise the TMC on methodological issues and value chain needs and perspectives. The SAC will include seats for FAO, LEAP and EU-PEF partners.

2.2 GFLI methodology

This guidance document describes the methodology for deriving LCI data. The methodology is the result of several years of development within different frameworks, such as:

- LEAP feed guidelines 2016
- Feed PEF database methodology May 2017
- Feed PEFCR version March 2018
- LEAP feed additives guidelines 2020

The requirements from these documents are brought together so that it can be used as a standalone reference document, where the user can find all necessary guidance on how to develop and maintain GFLI compliant datasets. This document and the GFLI database will be modified once updates in the above-mentioned documents are judged relevant.

2.3 GFLI-projects

Two main types of projects are distinguished: database developments and modelling developments. Also, three subtypes projects can be distinguished:

- Regional projects
- Sectoral projects
- Branded projects

Database development projects can either be a first development or an update of existing LCI datasets or databases. Modelling developments are about more detailed emission modeling of existing

LCI datasets or databases and can only be carried out for regional and sectoral development projects (Table *1*). Modelling updates, regarding general LCA methodology or emission modeling throughout the whole of the GFLI database are always initiated by the GFLI Board of Directors.

	Database development		Modelling development	
	First development	**Update**	**More detailed emission modelling**	**Update**
Regional	X	X	X	NA
Sectoral	X	X	X	NA
Branded	X	X	NA	NA

Table 1 Different types of GFLI projects

In the GFLI procedures document, guidance is given on how to initiate and organize projects. The procedures document also elaborates on the types of data development projects. Annex 1 gives a visual representation of the current coverage.

3 Methodology for deriving inventory data

3.1 Reference documents

The GFLI methodology is built on four reference documents:

- FAO LEAP feed guidelines 2016 (FAO, 2016)
- Feed PEF database methodology 2017 (Blonk et al., 2017)
- Feed PEFCR 2018 (European Commission, 2018a)
- LEAP feed additives guidelines 2020 (Livestock Environmental Assessment and Performance Partnership (FAO LEAP), 2020)

The LEAP feed guidelines are developed by the Livestock Environmental Assessment and Performance (LEAP) Partnership, a multi-stakeholder initiative whose goal is to improve the environmental sustainability of the livestock sector through better metrics and data. The LEAP Guidelines explain how LCA studies can be best performed.

The Feed Product Environmental Footprint Category Rules (PEFCR), developed in the context of the Product Environmental Footprint (PEF) pilot phase initiated by the European Commission (EC), define detailed requirements on how to conduct an LCA on feed in an unambiguous way. It is built on the LEAP feed guidelines but more directive. It sets requirements on the use of primary and secondary data, data quality management, LCA methodology rules, and the way how LCI data of supply chains need to be collected and modelled. The most recent LEAP guidelines are about the assessment of feed additives specifically.

The Feed PEF database methodology document sets the requirements on how specifically model datasets, consistent with the PEFCR.

The GFLI methodology adopts the framework and the rules of the feed PEFCR but:

- Prescribes the use of different background datasets than the PEFCR since the PEF data on energy, transport and chemicals cannot be used outside the scope of PEF studies.
- Allows for the use of deviating background data for specific regional database publication.
- Allows for the use of deviating emission modelling for specific regional database publication.
- Allows for more regular database updates than the PEF database for feed ingredients.
- Allows for the use of several life cycle impact assessment methods, like the Environmental Footprint (EF) methodology of the European Commission (European Commission, 2019; Fazio et al., 2018)

3.2 Feed ingredients and reference units

The GFLI database provides LCI datasets for feed ingredients that can be used in the formulation of compound feed or directly used at the farm (Figure 1).

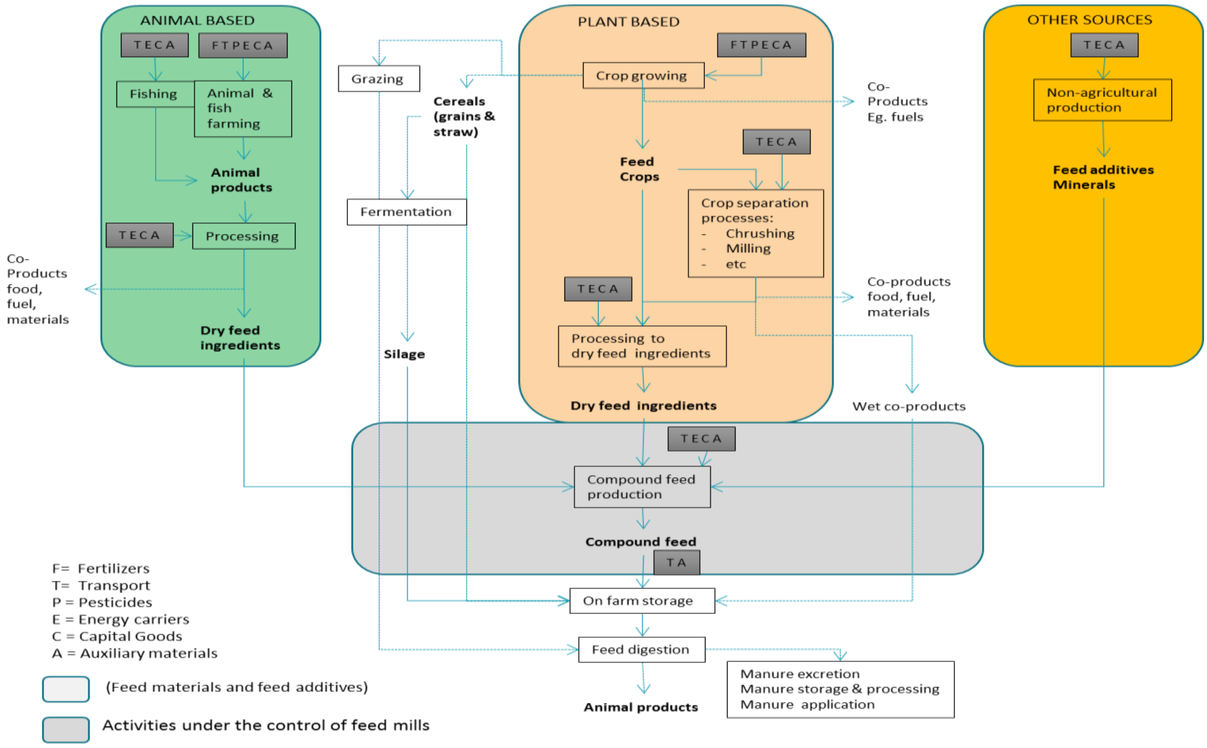

Figure 1 Overview of the production chain of compound feed and other feed flows entering the farm

The full lifecycle of production of feed ingredients that can be a used in compound feed is in scope (coloured boxes).

The reference unit of feed ingredients is 1000 kg of product as is. All data in the GFLI database are related to this reference unit.

Currently there are over 200 different feed ingredients in the GFLI database.

3.3 System boundaries

The LCA datasets collected and implemented in the GFLI database are data that refer to the operational primary production, processing, and transport processes of producing feed ingredients. Activities that are not directly related to the physical production operation, such as marketing, business travelling, commuter travelling, living at a farm, etc. are excluded. Depreciation of capital goods and machinery and use of consumables are included unless they can be excluded based on materiality, which is the case for processing of crops for instance.
Leading principle for data collection is that datasets should be as complete as possible and include all data points that are defined as required. The inclusion and exclusion of processes is further explained in sections 3.10 and 3.12.

3.4 Allocation at co-production

The allocation procedure in a multiproduct process (i.e. multifunctional process) is one of the most critical issues in LCA. “Allocation”, also called “partitioning”, solves the multi-functionality problem by splitting up the amounts of the individual inputs and outputs between the co-functions according to some allocation criteria, being a property of the co-functions (e.g., element content, energy content, mass, market price etc.) (JRC-IES & European Commission, 2010).
Avoiding allocation by system expansion and inclusion of avoided production, shall be applied when the avoided product can be unambiguously determined. That is for example the case when biobased energy carriers are produced that are supplied to a grid, for instance combined heat and power production.

Three types of allocation are supported by the GFLI database, in accordance with the Feed PEFCR:

- Economic (is preferred method in Feed PEFCR)
- Mass dry matter
- Energy content

3.5 Supported impact categories

LCI impact results are available in Excel format, which provides the environmental impact results. They are also available in .csv which provides the aggregated inventory results of all 962 deliverables for all three allocations according to the ReCiPe Midpoint Hierarchy method and the Environmental Footprint (EF) methodology of the European Commission. This method includes the following impact indicators: Global warming (Including LUC); Global warming (excluding LUC); Stratospheric ozone depletion; Ionizing radiation; Ozone formation, Human health; Fine particulate matter formation; Terrestrial acidification; Freshwater eutrophication; Terrestrial ecotoxicity; Freshwater ecotoxicity; Marine ecotoxicity; Human carcinogenic toxicity; Human non-carcinogenic toxicity; Land use; Mineral resource scarcity; Fossil resource scarcity; Water consumption.

3.6 Modelling framework

3.6.1 Default and alternative modelling (TIER levels)

Many emissions, especially at primary production are not measured but calculated flows where input activity data are connected to emission models. For example, the NH_3 emission at cultivation is calculated from the inputs of synthetic and organic N-fertilizers considering the type of fertilizer and the technique of application.

There are two levels of modelling possible in the GFLI database:

- Default emission modelling according to the rules of the PEF guidance document (European Commission, 2018c) on agricultural modelling are implemented in the Agri-footprint database (http://www.agri-footprint.com/users/#methodology) which is the source of the default data in the GFLI database. The PEF guidance document builds on other international methodology documents such as the IPCC for modelling of GHG emissions in agriculture.
- Regional specific modelling when data providers want to model their inventory data using a more detailed (higher TIER level) modelling approach.
- GFLI LCI datasets shall be calculated based on the default modelling. If data are developed based on alternative TIER levels, they shall be published separately.

3.6.2 Default background data and use of alternative sources

The background data for products and processes used at primary production, processing and transport originate either from the Agri-footprint database (Van Paassen, Braconi, Kuling, Durlinger, & Gual, 2019b, 2019a) or from data collected during GFLI projects. Which background data may be used is defined more specifically in sections 3.10, 3.11 and 3.12.

GFLI LCI datasets shall be calculated based on the use of default background data. “Data in” projects can adjust default background data to fit their project specific circumstances. They can request GFLI for a disaggregated and parameterized version of specific background data. This will allow development of background data with an improved data quality.

3.7 Data sources in relation to type of project

The three subtypes of projects require different types of data sources. For datasets of branded products more primary and/or improved secondary data are needed than for regional or sectoral data[1]. Table 2 and Table 3 give an overview of the minimal requirements for data sources per type of product (crops, animal farm products, primary processed products, and secondary processed products).

1 The requirements for branded products may be adjusted based on the pilot that is currently running.

Stages		Regional CROP/ Fisheries	Regional PROCESSED product (1 step)	Regional PROCESSED More steps	Sectoral CROP / fisheries	Sectoral PROCESSED product (1 step)	Sectoral PROCESSED More steps
Cultivation/ fishing	Cultivation activity data	**$SEC_{IMPPROVED}$**	$SEC_{Default}$	$SEC_{Default}$	**PRIMARY**	$SEC_{Default}$	$SEC_{Default}$
	Production of inputs	$SEC_{Default}$	$SEC_{Default}$	$SEC_{Default}$	$SEC_{Default}$	$SEC_{Default}$	$SEC_{Default}$
Transport	Market mix & Logistics		**$SEC_{IMPROVED}$**	$SEC_{Default}$		**$SEC_{IMPROVED}$**	$SEC_{Default}$
Animal farm	Farm activity data		**$SEC_{IMPROVED}$**	$SEC_{Default}$		**$SEC_{IMPROVED}$**	$SEC_{Default}$
	Production of inputs		$SEC_{Default}$	$SEC_{Default}$		$SEC_{Default}$	$SEC_{Default}$
Transport	Farm prod. mix & Logistics		**$SEC_{IMPROVED}$**	$SEC_{Default}$		**$SEC_{IMPROVED}$**	**$SEC_{IMPROVED}$**
Primary processing	Processing activity data		**$SEC_{IMPROVED}$**	$SEC_{Default}$		**PRIMARY**	**PRIMARY**
	Production of inputs		$SEC_{Default}$	$SEC_{Default}$		$SEC_{Default}$	$SEC_{Default}$
Transport	Product Mix & Logistics			**$SEC_{IMPROVED}$**			**$SEC_{IMPROVED}$**
Secondary processing	Processing activity data			**$SEC_{IMPROVED}$**			**PRIMARY**
	Production of inputs			$SEC_{Default}$			$SEC_{Default}$

Table 2 Minimal requirements for deriving regional and sectoral datasets

If a regional project is meant to generate datasets that existed already in the GFLI database, then the new data sources should have a higher data quality rating than the original data. This is phrased as "improved secondary data". If such data are not available, then primary data can be collected to fill in gaps.

If data are collected for a sector, they should be collected from representative (see chapter 3.8) production processes in that sector that reflect the actual performance of the sector in a certain period. Primary data collection is then required for the activity data of the production processes in that sector. The basic principle for branded data is using as much primary data as possible and needed for deriving meaningful results. So, the minimal requirements for primary data depend also on contribution in the overall impact and accessibility. Table 3 provides some provisional examples for required data sources for branded data.

In 3.10 and 3.12 the minimal data requirements for regional, sectoral and branded data are further elaborated.

	Branded soy beans	Branded soy bean meal	Branded palm kernel oil	Branded bone meal	Branded whey powder
Cultivation activity data on use of inputs, yields and allocation	PRIMARY	PRIMARY	PRIMARY	SEC$_{GFLIdefault}$	SEC$_{AFP}$ -- PRIMARY
Production of inputs for cultivation	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$
Market mix & Logistics to processing		SEC$_{IMPROVED}$	SEC$_{IMPROVED}$	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$
Animal Farm activity data on use of inputs, yields and allocation				SEC$_{IMPROVED}$	PRIMARY
Production of inputs for farming				SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$
Farm/fisheries product mix & Logistics to processing		SEC$_{IMPROVED}$	SEC$_{IMPROVED}$	SEC$_{IMPROVED}$	SEC$_{IMPROVED}$
Processing activity data on use of inputs, yields and allocation		PRIMARY	PRIMARY	SEC$_{GFLIdefault}$	PRIMARY
Production of inputs for processing		SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$
Logistics to secondary processing			SEC$_{IMPROVED}$	SEC$_{IMPROVED}$	
Secondary processing activity data on use of inputs, yields and allocation			PRIMARY	PRIMARY	
Production of inputs for secondary processing			SEC$_{GFLIdefault}$	SEC$_{GFLIdefault}$	

Table 3 Example branded datasets (draft). This table will be updated after the finalization of the pilot investigating requirements for branded products

3.8 Data sampling at primary data collection

Data sampling may be applied for the collection of primary data in case multiple production sites are involved in the production of the same product (e.g., in case the same feed ingredient comes from multiple production sites or in case the same process is outsourced to more than one subcontractor/supplier.

Stratified data sampling is often needed to deal with variation in (performance) of technologies.

The procedure to select a representative sample as a stratified sample is as follows:

1) define the population of operation
2) define if there is variability in (performance) of technologies homogenous sub-populations (stratification)
3) define the sub-samples at sub-population level
4) define the sample for the population starting from the definition of sub-samples at sub-population level.

The baseline approach for defining the sample size for branded data is to use the square root of the number of operations in the sub-population.

When primary data are collected as part of a sectoral project this sampling approach is guiding but it is possible to deviate with a sound argumentation. The sample size and sample definition shall be reported in the meta data.

3.9 Data quality measurement

Data quality measurement shall be conducted based on the data quality matrix, being developed in the EC feed database project (see Annex 3).
For the DQR measurement 4 Data Quality Indices (DQI) are used:

- Precision
- Time representativeness
- Technological representativeness
- Geographical representativeness

To evaluate the DQR, a division needs to be made in type of data and how they are interrelated. Data quality evaluation shall consider the contribution of the data points to the overall environmental impact.

The DQR evaluation includes activity data and the background data they relate with, being production of goods such as transport and electricity and combustion of fuels or other chemical conversion during processing. This gives the following set of evaluation points (Table 4).

Data type	DQR criterion
Activity data	Precision: P
	Time Representativeness: TiR
	Technology Representativeness: TeR
	Geographical Representativeness: GeR
Background data	Time Representativeness: TiR
	Technology Representativeness: TeR

Table 4 DQR criteria used in connection to activity data and background data for production and combustion/conversion

Annex 3 gives the overview of the full DQR matrix. The DQR information needs to be gathered during the data collection process. Sections 3.10 and 3.12 give more specific guidance on collecting DQR data at cultivation and processing.

3.10 Modelling of cultivation

3.10.1 Basic approach defining process sheets for cultivation in LCI databases

The LCI elementary flows of cultivation are not measured but calculated by combining activity data and models (Figure 2*)*.

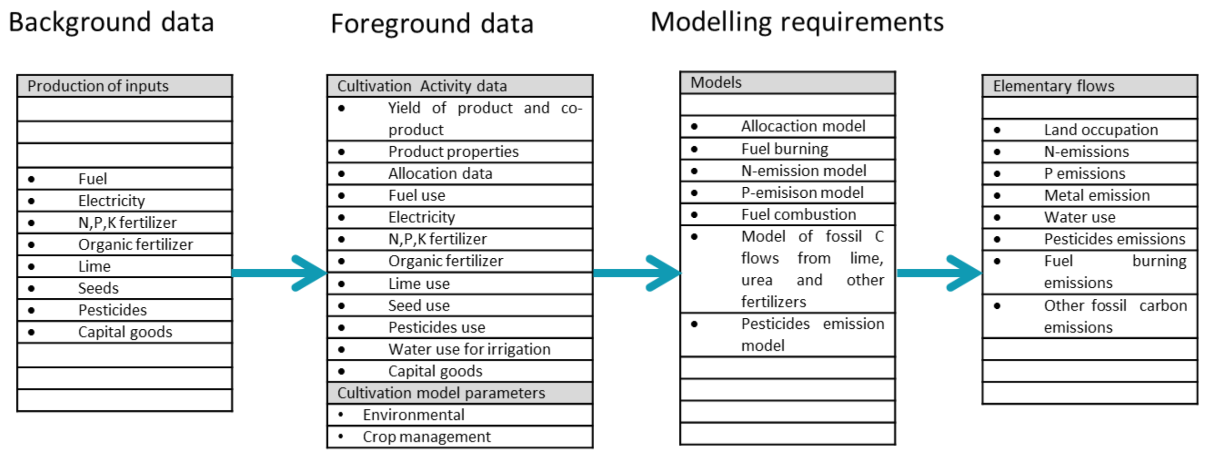

Figure 2 Schematic overview of how elementary flow are modelled at cultivations

Depending on the type of emission model (TIER level) and way of allocation, additional information needs to be collected on:

- Plant products, co-product and plant residue properties (energy content, or price when applying energy or economic allocation or N- content of plant residues for N emission modelling);
- Crop rotation relationships (assigning activities that are not targeted to one crop but to maintain fields such as manure management, drainage);
- Management practices (soil management in relation to N_2O and CO^2 emissions such as tillage/ no tillage);
- Environmental conditions (e.g., ground water level, soil type, water balance).

In the following sections the GFLI method for collecting and modelling cultivation data will be further explained.

3.10.2 System boundary: included activity data

Table 5 shows the activity data that needs to be included at cultivation.

Included	Excluded
• Fuels use • Electricity use • N, P, K Fertilizer use • Organic fertilizer (manure and others) use • Lime use • Use of organic fertilizers or soil improvers • Use of Pesticides on the field and at storage • Use of irrigation water • *Seed use* • *Depreciation of capital goods for machinery and storage* • *Packaging of fertilizers and pesticides.*	• Other consumables used during cultivation, except when they have an anticipated material contribution. • Activities related to living at the farm • Activities related to other business (e.g. producing wind energy)

Table 5 Included and excluded activities and elementary flow in cultivation, processing of crops and other production (for italic included default background data may be used)

It is common practice to exclude other consumables at cultivation. These involve mostly negligible quantities in terms of environmental contributions. Activities related to living at the farm (for instance fuel and electricity use) are considered as out of scope but are sometimes hard to distinguish from cultivation related activities (see section 3.10.5.6.).

Activities related to energy production at the farm that are not related to the mass flows being generated due to cultivation (e.g. wind or solar power) are only accounted for, when used on farm.

Some activity data are more important than others. The italicized data points in Table *5* may be collected. However, if these data cannot be collected in practice, default background data may be used from the GFLI default background datasets, for example seed inputs (See annex 5), transportation distances capital goods (Blonk et al., 2017) or packaging material of fertilizers and pesticides (Durlinger, Koukouna, Broekema, van Paassen, & Scholten, 2017).

3.10.3 Average situation (steady state)

Cultivation data are collected over a period sufficient to provide an average assessment of the life cycle inventory associated with the inputs and outputs of cultivation that will offset fluctuations due to seasonal differences. Table 6 gives an overview how the EC tender requirements are applied in the data collection process of the main data sources:

Requirement
1. For **annual crops**, an assessment period of at least three years shall be used (to level out differences in crop yields related to fluctuations in growing conditions over the years such as climate, pests, and diseases). Where data covering a 3-year period is not available i.e. due to starting up a new production system (e.g. new greenhouse, newly cleared land, shift to other crop), the assessment may be conducted over a shorter period, but shall be not less than 1 year. Crops/plants grown in greenhouses shall be considered as annual crops/plants unless the cultivation cycle is significantly shorter than a year and another crop is cultivated consecutively within that year.
2. For **perennial plants** (including entire plants and edible portions of perennial plants) a steady state situation (i.e. where all development stages are proportionally represented in the studied time period) shall be assumed and a 3-year period shall be used to estimate the inputs and outputs. Where the different stages in the cultivation cycle are known to be disproportional, a correction shall be made by adjusting the crop areas allocated to different development stages in proportion to the crop areas expected in a theoretical steady state. The application of such correction shall be justified and recorded.
3. For crops that are grown and harvested in **less than one year** (e.g. lettuce produced in 2 to 4 months) data shall be gathered in relation to the specific time period for production of a single crop, from at least three recent consecutive cycles.

Table 6 Implementation of the (steady state) average requirement in the source databases used for the GFLI database

3.10.4 Assigning inputs and outputs to crops and allocation of crop co-products

At an arable farm, mostly different crops are grown in a certain sequence (crop rotation), also quite often livestock is produced at the same farm. Furthermore, harvested plants can generate multiple co-products such as seeds and straw. To assign the different activities and inputs to specific crops and co-products the LEAP feed guidelines (FAO LEAP, 2015a)[2] are followed. Table 7 shows how the different allocation topics are handled in the GFLI database.

2 See figure 7 on page 37 of LEAP feed guidelines

Allocation topic	Baseline GFLI approach	Alternative options
Activities related to crop rotation • Organic fertilizer application (manure and others)	Nutrient content of manure application per year on arable land is divided over all crops based on surface contribution. No division is made in the mineral and organic fraction in manure.	See 3.10.5.8
• Energy production from co-products from farming	Relevant for palm fruit bunches and sugar cane bagasse. Energy recovery has been accounted for in reduction of fossil energy use during production	
• Straw from cereals	Allocation has been applied based on three different keys (economic, energy content and mass).	.

Table 7 Handling of allocation topics in the source databases

3.10.5 Collecting activity data

This section gives guidance on the data that needs to be collected and the sources that can be used. The following data shall be collected or derived:

- Quantitative data on activities and products
- DQR (Data Quality Rating) data
- Meta data[3]

There is a template available for data collection, this template is available for data-in providers. This template can be adjusted so that it fits the purposes of a project.

The following sections give a further explanation on the activity data to be collected. How to apply the data quality rating is explained in Annex 3.

Per activity data point there are three approaches. These approaches affect the DQR of the dataset, specifically the Precision (P), Technical representativeness (TeR) and Geographical representativeness (GeR) criteria of the DQR (see Table 19 in the Annex). The possible approaches are (Table 2):

- Specific approach – improved data compared to background databases, existing of (partly) primary data
- Semi specific approach – improved data compared to background databases, but not necessarily (partly) primary data
- Default approach – default background databases

Regional projects should at least use a semi specific approach for the most contributing activity data points:

- Yields of main and co-products,
- Prices of main and co-products,
- Fertilizer,
- Organic fertilizer,
- Energy,
- Irrigation water use.

Sectoral projects should collect primary data for the most contributing activity data.

Branded projects (e.g. cultivation according to a certification scheme) should collect primary data for all necessary activity data listed in Table 5.

3 Meta data describe the data and the process of data generation. Meta data include reference year(s), technology description, deviations from GFLI methodology (if applicable), allocation method, data sources used, sample size/ % production covered, use advice for dataset.

3.10.5.1 Yield of the main product

Yield is defined as the net weight of a product harvested per surface area of farm fields.

Crop yields should be collected based on reliable statistical sources, preferably publicly available. Comply to the requirements on steady state, time frame and allocation as explained in the sections 3.10.3 and 3.10.4.

Specific approach: yields shall be based on recent measurements, accountant reports, or statistics and surveys that are based on reliable validated data and represent the cultivation in scope.

Semi Specific approach: yield data shall be based on well-established data sources collected in the region by statistical institutions, governmental or research bodies.

Default approach: for crops FAOstat yield statistics (FAO, 2017) can be used. A 3 or 5 year yield average will be used in line with the requirements set in chapter 3.10.3. In case this specific crop is not reported in FAOstat, a crop similar to the crop in scope might be used as a proxy. This should be documented in the meta data and accounted for in the data quality rating.

3.10.5.2 Yield of the co-product

To quantify the yield of co-products is usually more challenging because yields of co-products are not always available in statistics.

Specific approach: yields shall be based on recent measurements, accountant reports, or statistics and surveys that that are based on accountable validated data and represent the cultivation co-product in scope.

Semi Specific approach: yield of co-products can be based on measurements, statistics, reports, or any other reliable information from which the yield could be derived. Contrary to main products, there is usually little information on the yield of co-products in statistics and reports. Therefore, the following semi-specific options can be considered.

For crops, derive yield of co-products from an assumption on fractions of harvested above ground biomass or use straw-to-grain ratios. Like yield statistics, the straw-to-grain ratio of specific products can be collected from reliable sources (Copeland & Turley, 2008; Mcdonald, 2010; Searle & Bitnere, 2017).

Default approach: Assumes a fixed straw-to-grain ratio (e.g., in Agri-footprint 4.0 this was 0.6 for cereals).

3.10.5.3 Product properties

Product properties concern chemical or physical aspects of feed ingredients which are either relevant for calculating the overall feed nutritional data, for allocation or heavy metal flows (see chapter 3.10.6). Table 8 shows the data that need to be collected for crops and co-products. There are three categories of data points distinguished:

- Shall, without this data the data set cannot be implemented in the GFLI database.
- Should, data should preferably be provided, if not available the defaults are used from a relevant feed ingredients nutritional table or the Feedipedia from FAO.
- May, data should preferably be provided, if not available defaults are used.

	Unit	Specific	Semi-specific
Price	Money unit/weight unit	Shall	Should
Dry matter content	%	Shall	Should
Caloric value	MJ HHV/kg	Shall	Should
N-content	weight % on as is basis	Shall	Shall

P-content	weight % on as is basis	Shall	Shall
C-content	weight % on as is basis	May	May
Cd-content	weight % on as is basis	May	May
Cr-content	weight % on as is basis	May	May
Cu-content	weight % on as is basis	May	May
Hg-content	weight % on as is basis	May	May
Ni-content	weight % on as is basis	May	May
Pb-content	weight % on as is basis	May	May
Zn-content	weight % on as is basis	May	May

Table 8 Data to be collected for crop (co)- products

3.10.5.4 N in crop residues

The quantification of nitrogen in crop residues is important because it results in nitrous oxide and nitrate emissions, as shown in Section 3.10.6.

Specific and semi approach
The amount of nitrogen from crop residues can be calculated based on default data from national or regional guidelines or studies. An example of useful guidelines is the methodology developed for National Inventory Reports for IPCC climate impact monitoring. The calculation of nitrogen from crop residues is then more geographic specific, compared to the default approach which is based on IPCC (see next paragraph).

Default approach
In the default approach nitrogen from crop residues is calculated using IPCC estimations of N added to soils from crop residues per crop(type) (IPCC, 2006). From this the amount of “Above ground dry matter” (AGDM) and “Below ground dry matter” (BGDM) are calculated. AGDM and BGDM together form the total amount of crop residues, from which the amount of nitrogen from crop residues can be quantified. For the EC and US database these IPCC defaults were used without alterations. For the Canadian database, the amount of co-product is subtracted from AGDM to determine the amount of crop residues that remain on the field. The later approach will be the default approach for future studies. In a future revision of the EU and US database, the amount of crop residues will also be updated with the new default approach.

3.10.5.5 Allocation data for co-production

Three ways of allocation are supported for which data need to be collected:

- Economic allocation → prices at exit farm of products and co-products
- Energy-content based allocation → caloric values of product and co-products
- Mass based allocation → dry matter yields of products and co-products

Specific and semi specific approach: Prices needed for allocation shall be representative for the region in scope and shall be average prices for a recent 3 years-period. Taxes, transport, and insurance costs should not be included in the price. Take notice that the absolute prices are not relevant but the relative price difference between co-products. Caloric values and dry matter yields should be based on recent measurements, accountant reports, or statistics and surveys that that are based on accountable validated data. It is important to use complete and consistent data for the range of co-products. Incomplete information of data from separate sources may lead to incorrect results.

Default approach: In the default approach the allocation fractions in Annex 5 are used.

3.10.5.6 Direct energy use

Direct energy use involves all on farm energy use related to the production and storage of the crop. Direct energy use is broken down into two different activities: energy use related to field operations and energy use related to the storage and possible drying of the crop. Drying and storage can take place at farm or at another location. For both activities, data can be gathered in multiple ways. Under energy use at farming also the usage of lubricant oils for tractors and machinery is included.

3.10.5.6.1 During field operations

Specific approach: data on direct energy use comes from bookkeeping data of the farms allocated to specific activities. This can be available in literature or statistical platforms. Another option is to use measured data for activities from for instance the machinery used.

Semi-specific approach: estimating energy use based on frequency of activities related to energy use. For this approach, the frequency of certain activities needs to be reported. Energy use per specific activity might be collected from literature or from default list provided in the appendix. (See Annex 5)

Default approach: the default approach uses an energy model for cultivation that has been developed in a cooperative project between Blonk Consultants and Wageningen University (publication in preparation). The model calculates the direct and indirect energy use related to the cultivation of a specific crop in a specific country. The included activities are tillage, seedbed preparation, sowing, irrigation, manure application, fertilizer application, pesticide & weed application, harvesting and post harvesting operations. The model uses specific parameters for different crops and countries, which results in a specific energy input for each crop country combination.

3.10.5.6.2 During storage

Specific approach: data regarding storage needs to be collected specifically and separately for the feed ingredient. Similarly, as for cultivation, energy related to storage can be collected from bookkeeping information or be measured.

Semi-specific approach: in the semi-specific approach the dry matter content of the feed ingredient at harvest and at storage should be determined. In case the dry matter content of the feed ingredient after storage exceeds that of the harvested feed ingredient, the feed ingredient was dried. The amount of water that was evaporated is calculated from the dry matter content at harvest and storage. Using a default energy input per kg of water evaporated, the total amount of energy use for storage can be determined. The energy default for the semi-specific approach is 1 kWh electricity and 7 MJ fuel oil per kg water evaporated (Kool, Marinussen, & Blonk, 2012).

Default approach storage: the default approach uses fixed energy use for storage (see Table 30 in the Annex).

The following tables (Table 9 and Table 10) give an overview of the different energy sources used during field operations and storage for which data need to be collected.

Energy use	Unit
Electricity	kwh /hectare*yr crop under study and if a specific mix is bought (green electricity), the mix can be reported.
Diesel	Liters or kg/hectare*yr crop under study and caloric value (HHV/Liters or kg)
Fuel oil	Liters or kg /hectare*yr crop under study and caloric value (HHV/Liters or kg)
Lubricant oil	Liters or kg/hectare*yr crop under study and caloric value (HHV/Liters or kg)
Other oils	Liters or kg of specified oil/hectare*yr crop under study and caloric value (HHV/Liters or kg)
Natural gas	m^3 /hectare *yr and caloric value (HHV/m^3)
Other gas types (eg propene)	m^3 of specified gas/hectare*yr crop under study and caloric value (HHV/ m^3)
Biofuels solids	Specify per case type of biofuel, unit, and caloric values
Biofuels fluid	Specify per case type of biofuel, unit, and caloric values
Biofuel/fossil fuel mixes	Specify per case unit and caloric values

Table 9 Energy use for cultivation at the farm. For lubricant oils defaults may be used

Energy use	Unit
Electricity use	kwh / ton product*
Fuel	(Liters or kg)** / ton stored product*
Other oils	(Liters or kg)** / ton stored product*
Natural gas	m^3** / ton stored product*
Other gas types (eg propene)	m^3** / ton stored product*
Biofuels solids***	(Liters or kg)** / ton stored product*
Biofuels fluid***	(Liters or kg)** / ton stored product*

Table 10 Energy use for storage

** after storage dry matter content as used or sold and including losses*
*** define caloric value per weight or volume unit*
**** specify type of biofuel*

Activities related to living at the farm (for instance fuel and electricity use) are considered as out of scope but are sometimes hard to separate from cultivation related activities.

3.10.5.7 Fertilizer use (N, P, K)

Application of synthetic fertilizers to crops shall be based on crop specific use statistics or derived from agronomic surveys or agronomic guidance documentation representative for the region in scope of the study.

When other information is used than crop specific use statistics, for instance agronomic reference documents, use scenarios should be derived considering the background application of manure or other organic fertilization applied for maintaining soil fertility. The NPK amount needs to be translated to specific fertilizer types (Table 11) this can be done in multiple ways:

Specific approach: fertilizer use is based on recent measurements, accountant reports, or statistics and surveys that are based on reliable validated data and represent the cultivation in scope. Ideally, the specific types of synthetic fertilizer are similar as those shown in Table 11. In case other types of fertilizer are used, the content of N, P (in P_2O_5-eq) and K (in K_2O-eq) needs to be specified. These inventoried fertilizers shall then be mapped to fertilizers for which background data exists. If required, a quantitative correction will be performed based on the concentration of the product, to match the nutrient quantity in the inventoried to the quantity in the background data.

Semi-specific approach: amounts of specific synthetic fertilizer use are calculated using NPK application rates of representative agronomic reference documents in combination with regional statistics on the type of fertilizers sold within that specific region or country. For this approach it is mandatory to provide at least specific NPK information. Regional statistics on fertilizer types sold for a specific region might be provided or alternatively default data from International Fertilizer Association (IFA, 2017) might be used. The specific fractions of fertilizer for N, P and K, in combination with the NPK totals, could then be used to quantify the amounts of specific type of fertilizers. Again, the inventoried NPK data will be connected to a similar fertilizer shown in the Table 11. A correction will be performed based to match the amount of NPK in the product if necessary.

Default approach: NPK data from Agri-footprint methodology are used to determine nutritional needs by fertilizers. By combining the default NPK data with statistics from the International Fertilizer Association (IFA, 2017), amounts of specific fertilizer types are inventoried.
Table 11 gives an overview of available fertilizers in the background database. When other fertilizers are applied, the product name and the content of N, P, K shall be given.

Fertilizer name	Unit
N from artificial fertilizer	Kg N /ha
P from artificial fertilizer	Kg P_2O_5-eq /ha
K from artificial fertilizer	Kg K_2O-eq./ha
Ammonia, as 100% NH3 (NPK 82-0-0)	Kg product/ha
Ammonium Nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0)	Kg product/ha
Ammonium Sulphate, as 100% $(NH_4)2SO_4$ (NPK 21-0-0)	Kg product/ha
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0)	Kg product/ha
Di ammonium phosphate, as 100% $(NH_3)2HPO_4$ (NPK 22-57-0)	Kg product/ha
Liquid urea-ammonium nitrate solution (NPK 30-0-0)	Kg product/ha
NPK compound (NPK 15-15-15)	Kg product/ha
Phosphate rock (32% P_2O_5, 50% CaO) (NPK 0-32-0)	Kg product/ha
PK compound (NPK 0-22-22)	Kg product/ha
Potassium chloride (NPK 0-0-60)	Kg product/ha
Potassium sulphate (NPK 0-0-50)	Kg product/ha
Single superphosphate, as 35% $Ca(H_2PO_4)_2$ (NPK 0-21-0)	Kg product/ha
Triple superphosphate, as 80% $Ca(H_2PO_4)_2$ (NPK 0-48-0)	Kg product/ha
Urea, as 100% $CO(NH_2)_2$ (NPK 46.6-0-0)	Kg product/ha
Lime Fertilizer	Kg $CaCO_3$/ha
Dolomite	Kg $CaMg(CO_3)_2$/ha

Table 11 Available fertilizers in the GFLI database

3.10.5.8 Organic fertilizer application

Organic fertilizers (manure and other sources) are applied to maintain soil fertility on the farm. Manure and organic fertilizers may be applied according to a crop rotation scheme. The annual application is then often concentrated to a share of the plots which is changing over the years so that every plot gets its addition of organic matter through the years. For the crop rotation situation allocation rules should be applied as explained below.

Specific approach: the use of manure is based on recent measurements, accountant reports, or statistics and surveys that are based on accountable validated data and represent the crop and farms in scope. Data should be collected for every organic fertilizer type. Additionally, data needs to be collected on the nitrogen and phosphorus content given. Heavy metal content of the different types of manure may be collected but this is not mandatory.

If Organic fertilizer is applied in a crop rotation scheme the nutrient application is divided over all crops in the crop rotation scheme on the basis of share in area, except for the mineral N fraction which is allocated solely to the crop of application.

The following calculation rules apply for fertilization of N (BSI, 2012).

Formula 1 (Calculating N application to a crop as part of a crop rotation scheme)
Total N from Organic Fertilizer applied to the plot where crop A stands = NmOA + NcrA + aA/aT x NoO

- NmOA = Mineral nitrogen from organic fertilizer applied to crop A (kg N/ area unit)
- NcrA = Nitrogen from crop residues of crop A (kg N/ area unit)
- aA = area of crop A (area unit)
- aT = total area of crop rotation system (area unit)
- NoO = Organic nitrogen from organic fertilizer applied on all area (kg N/ area unit)

All other fertilizing elements supplied using organic fertilizers, including green manure, are calculated by:

Formula 2 (Calculating Fertilizer application to a crop as part of a crop rotation scheme)

$F_{\text{applied to crop}}\ A = aA/aT \times FO$

Where

- aA = area of crop A (area unit)
- aT = total area of crop rotation system (area unit)
- FO = Organic fertilizer applied on all area (kg FO / area unit)

Semi-specific approach: There are several types of semi-specific approach. One example is where the farm specific data are replaced by regional or country data that are collected by a public or industry body that monitors manure application in a certain region together with the crop area. This data can consecutively be attributed to crops based on the same allocation rules as in the specific approach. If information on the composition of the manure is lacking, then default compositions are used (see Table 12).

Default approach: the default approach uses the methodology described in the report of Feedprint (T. Vellinga et al., 2013). It relies on statistical information of manure (FAO, 2018), in which is assumed that:

Manure from ruminants (beef, dairy, sheep, and goats) comes from systems that are partly grass based, especially beef cattle, sheep and goats are kept in more or less marginal grassland areas. The manure from grazing animals (dairy and beef cattle, sheep, and goats) is returned to grasslands. The manure of housed beef cattle, sheep and goats is not expected to be applied on arable land. The largest fraction will return to grassland areas, the remainder is considered negligible. So nitrogen (and P and K) of beef cattle, sheep, and goats is considered not to be applied on arable land (T. V. Vellinga, Blonk, Marinussen, Zeist, & Boer, 2013).

The amount of manure in combination with the default nitrogen, phosphorus and heavy metal contents of manure are used to determine the emissions associated to manure use. The total amount of manure and total N and P content used for this method is specific for poultry and porcine manure (Wageningen UR, 2017).

	Specific	Semi-specific
Amount of poultry manure (kg/hectare)	Shall	May
N-P content (N/P / kg poultry manure)	Shall	Shall
Heavy metals (mg / kg poultry manure)	Should	May
Amount of porcine manure (kg/hectare)	Shall	May
N-P content (N/P / kg porcine manure)	Shall	Shall
Heavy metals (mg / kg porcine manure)	Should	May
Amount other organic fertilizer (kg/hectare)	Shall	May
N-P content (N/P / kg organic fertilizer)	Shall	May
Heavy metals (mg / kg other organic fertilizer)	Should	May

Table 12 Overview of data requirements for organic fertilizer application for the different approaches

3.10.5.9 Lime and dolomite use

Lime and dolomite (or other $CaCO_3$ containing fertilizers) are used for managing acidity of the soil. The application depends on soil type and type of crop.

Specific approach: application of lime and/or dolomite is quantified based on farm specific use statistics or derived from agronomic surveys or guidance documentation representative for the region in scope of the study.

Semi-specific approach: amount of lime and/or dolomite is based on the total amount applied within a specific region divided by the amount of arable area within that specific area.

Default approach: default lime use is 400 kg/hectare and can be applied for all agricultural crops, based on assumptions made in Feedprint (T. V. Vellinga et al., 2013).

3.10.5.10 Water use for irrigation and other water use

Like all other activity data that can be collected, water use for irrigation and other water use can be determined in three different ways:

Specific approach: region and crop specific data on the irrigation water applied to fields need to be collected. This data can be based on measurements, statistics, reports, or any other reliable information. Any other water use related to the cultivation of the crop might be included as well.

Semi-specific approach: the amount of irrigation water applied to the fields can be based on region specific data. This could be based on the total amount of water used for irrigation divided by the amount of arable area within the specific region.

Default approach: if no better data is available the amount of irrigation water is based on the 'blue water footprint' assessment data (Mekonnen & Hoekstra, 2010). The blue water footprint refers to the volume of surface and groundwater consumed resulting from the production of a crop. The model uses grid-based dynamic water balances, daily soil water balances, crop water requirements, actual water use and actual yields. The water footprint of crops have been published per country in m3/ton of product (Mekonnen & Hoekstra, 2010). Combined with 5-year average FAO yields (2009-2013) the blue water footprint is calculated in m^3/ha.

3.10.5.11 Seed use

Seed use refers to the amount of start material required for the cultivation. Data for this can be collected in different ways:

Specific approach: region and crop specific data on the seed use can be based on measurements, statistics, reports, or any other reliable information.

Semi-specific approach: amount of seed used can be collected from all kinds of reliable information sources from other regions. The data should be at least crop specific.

Default approach: this approach uses crop specific global average seed input based on data from FAOstat (FAO, 2017). Although country specific can be used as well, analysis showed that there are huge variations between seed input for countries for the same cultivation.

3.10.5.12 Pesticides use

Pesticides data are often hard to collect, due to insufficient statistics. Since pesticides use is strongly influenced by legislation and regional risk factors, which can change year by year, it is necessary to collect country specific information. In many situations, expert judgement of agricultural advisory organizations is needed. Information becomes of better quality when different types of sources are combined. For example, combining expert judgement with national statistics on pesticides sales for agriculture and usage surveys.

Specific approach: collect crop and region-specific data of pesticide use.

Semi-specific approach: collect pesticide data from, other regions (preferably neighboring regions), or collect data from crops from the same crop-type as a proxy.

Default approach: crop average pesticide data of available crops same crop-types are used as a proxy.

3.10.5.13 Depreciation of capital goods

Capital goods include all farm buildings, floorings, roads at the farm and machinery that is needed for practicing cultivation and storage activities.

Collection of capital goods data is not mandatory. If no data is collected GFLI defaults shall be used.

3.10.6 Modelling of emissions of N, P, metals, and pesticides

The default method for emission modelling of N, P, metals, and pesticides is described in Annex 5.

If a project wants to propose an alternative way of modelling, the method should be described in detail and provided in a well-documented excel sheet.

Data can be published in the GFLI database in a regional database.

3.10.7 Choice of background data for production of farm inputs

The provided LCI data on farm inputs (fertilizers, manure, energy, pesticides, water, seeds) will be linked to the background data that are available in the GFLI database. A project can provide suggestions on using alternative background data or can develop additional background data if specific fertilizers, manure, energy, pesticides, water or seeds are used that were not available in the GFLI background database.

Annex 6 gives an overview of background data sets for production and combustion.

3.11 Fisheries and animal farming

3.11.1 Fisheries

This section describes the modelling rules for fisheries which are derived of The Guidance from the seafood lifecycle inventory database – Methodology and Principles and Data quality requirements (A.S Hognes et al 2018).

3.11.1.1 Data collection

Fisheries consists of all activities related to catching, landing, and sorting of the fish species for further processing as a feed ingredient.

Table 13 gives an overview of the inputs and outputs to be included or excluded.

Included	Excluded
• Landed fish • Fuels use • Auxiliary materials (anti foulings, baits)	• Other auxiliary materials adding up to less than 1% of mass contribution • Depreciation of vessel

Table 13 System boundaries for fisheries

The data for fisheries should be collected for a specific zone (FAO catch zone and subdivisions) and being representative for a 3 year-period (averaging out yearly variations in catches) and fishing technology.

3.11.1.2 Allocation to co-products

The PEFCR Marine Fish for human consumption is in development. In draft versions of the PEFCR mass allocation is applied for landed fish by default. Mass allocation is applied for allocation of landed fish in the context of the GFLI database.

3.11.2 Animal farming

This section describes the modelling rules for animal farm products that are processed to feed ingredients. The modelling rules are derived from FAO LEAP guidelines (FAO LEAP, 2015b, 2016; LEAP, 2015) and the PEFCR for dairy (European Commission, 2018b) and the PEFCR for Red Meat (TS Red meat pilot, 2016). These guidelines can be consulted for modeling of animal husbandry for dairy, meat and eggs.

3.11.2.1 Data collection

Animal farming consists of all activities related to the production and reproduction phase of animal farming. Per unit of animal product coming from a farm the pre-stages should be proportionally represented.

Table 14 gives an overview of the inputs and outputs to be included or excluded.

Included	Excluded
• Input: Output mass balance of animal (co-) products (incl. dry matter contents) • Allocation data (as per 3.10.2.2) • Feed ingredients production lifecycle • Daily ration of compound feed, additives and roughage • Enteric fermentation • Mortality rate • Fuels use • Heat/ Electricity use • Manure management	• Other auxiliary materials adding up to less than 1% of mass contribution • Depreciation of housing system

Table 14 System boundaries for animal husbandry

The data for animal husbandry should be collected for a specific region and the animal products are used as input for processing.

The default data for animal husbandry in the GFLI database originate from the Agri-footprint database (Van Paassen et al., 2019b, 2019a). Data for animal husbandry is available for bovine, porcine, broilers and layers. These data shall be applied for animal farm products unless better data are available.

There are several approaches possible, for the collection of farm data:

Specific approach required for branded products. Representative farm data need to be collected including all activity data points included in Table 14.

Semi specific/ default approach for sector- and region- specific products use of default farm data available in background databases is allowed.

The implemented approach shall be specified in the meta data. The more specific the approach the better the data quality rating.

3.11.2.2 Allocation to co-products

For dairy, a specific allocation method is applied: the biophysical allocation (European Commission, 2018b).

For poultry, economic allocation is applied, as suggested by the LEAP guidelines (LEAP, 2015).

For pigs and beef cattle, economic allocation is applied, as suggested by the PEFCR Red Meat (TS Red meat FCR, 2019).

Cadavers from animal husbandry systems are considered as waste, which means that no environmental impact is allocated to them. The approach for manure is through cut-off, resulting in no environmental burden or benefit attributed to manure.

3.12 Modelling of processing

Crops and animal products are processed into feed ingredients.

3.12.1 Modelling of processed plant-based products

Most of the processed feed ingredients are made of crops, split into different co-products in a processing plant. Examples of such food processing are the wet and dry milling of grains, the pressing and crushing of oil seeds and beans, or the sugar production. A limited set of the feed ingredients also concern (co-)products from further processing steps, such as oil refining, flaking, or heat treatment. Finally, processed animal-based products are also used as feed ingredients. Further explanation on the animal farm production and slaughtering can be found in section 3.11.

Processing to feed ingredients is mostly happening in large scale processing facilities with limited input of other raw materials. In several cases processing aids shall be included such as hexane at crushing or, acids at wet milling or calcium carbonate at sugar production. Processing aids are often used in small quantities. This makes the energy inputs the predominant activity data during processing.

3.12.1.1 Data collection

The processing stage consists of all steps from the provision of the crops, the processing of the crops and finally the storage of the feed ingredients before delivery to the client.

Table 15 gives an overview of the inputs and outputs to be included or excluded.

Included	Excluded
• Input: Output Mass balance (incl. dry matter content) • Price of (co-)products • Cultivation data • Crop input mix of originating countries • Transport (distance per transport means) • Fuels use • Heat/ Electricity use • Water use • Wastewater treatment only for wet processes • Organic waste & losses • Auxiliary materials (processing aids)	• Auxiliary materials adding up to less than 1% of mass contribution • Consumables used at the plant not used as a raw material or auxiliary material • Packaging if occurring

Table 15 System boundaries for processing of crops

In the current GFLI database 10 different processing technology datasets are included. These datasets originate from Agri-footprint (Van Paassen et al., 2019b, 2019a). Table 16 gives an overview of the processing technologies and auxiliary materials available in the GFLI database.

Process	Auxiliary materials considered	Current source of activity data used in Agri-footprint
Animal rendering	None	(van Zeist et al., 2012a)
Fish rendering	Sodium hydroxide Formaldehyde Ethanol Sulfuric acid Nitric acid Hydrochloric acid	(van Zeist et al., 2012a) (Hognes, Tyedmers, Krewer, Scholten, & Ziegler, 2018)
Cereal fermentation	None	(van Zeist et al., 2012b)
Crushing oilseeds (pressing)	None	(van Zeist et al., 2012c)
Crushing oilseeds (solvent)	Hexane Water	(van Zeist et al., 2012c) (Schneider & Finkbeiner, 2013)
Oil refining	Bleaching earth Phosphoric acid Sulfuric acid Active carbon Sodium hydroxide	(van Zeist et al., 2012c) (Schneider & Finkbeiner, 2013)
Dry milling	Water	(van Zeist et al., 2012d)
Sugar production	Limestone	(van Zeist et al., 2012f)
Wet milling	Water	(van Zeist et al., 2012g)
By-product processing food industry	None	(van Zeist et al., 2012e)

Table 16 Overview of different processing techniques and auxiliary materials available in the GFLI database

For collecting data in sector, regional and branded product "projects" the following approaches are possible:

Specific approach: This approach shall be applied for branded product "projects" which require primary data for all inputs:

- Mass balance and prices
- Cultivation data
- Crop mix of originating countries
- Transport (distance per transport means)
- Fuels use
- Electricity use
- Water use
- Wastewater treatment only for wet processes
- Organic waste & losses
- Auxiliary materials (processing aids)

In certain cases, where it can be substantiated (e.g. by previous LCA study results) and documented, some of the inputs are not significant to the impact of the process. These data points may be considered not relevant.

Semi specific approach: This approach can be used for sector- or regional- specific data, which requires primary data collection for:

- Mass balance and prices
- Fuels use
- Electricity use
- Water use
- Wastewater treatment only for wet processes
- Organic waste & losses
- Auxiliary materials (processing aids).

Default approach: In this approach the following steps are taken:

- Mass balance and prices are derived from literature (see Table 16).
- The market mix of crops is formulated based on the FAO trade statistics. The market mix for each raw material is based on domestic production and trade statistics per country. Sourcing countries in the market mix for which no background data is available, are removed and the mix is configured accordingly to avoid data gaps. The final inventoried countries cover at least 50% of the market mix.
- For the impact of transporting the raw materials from field to the processing facility, default data on transportation distances and transportation modes are used (see Annex 7).
- Use of fuels, electricity, water, and auxiliary materials are derived from literature and connected to country-specific production data when available, else global average datasets are used.

The implemented approach shall be specified in the meta data. The more specific the approach the better the data quality rating.

3.12.1.2 Assigning inputs and outputs (allocation) to co-products

At processing, economic allocation is specified according to the LEAP feed guidelines (FAO LEAP, 2015a) which mandate the following steps:

Step 1. Determine if your feed ingredient can be considered as a zero-allocation product. This is the case when two conditions are met: a) the product is sold as it is at the point of production (i.e. prior to drying or other modifications) and has a very low contribution to the turnover of the entire basket of co-products of the same process sold by the company; b) the (co-)production and upstream process is not deliberately modified for generating the co-products. Examples of zero-allocation products are wet and dry products from the consumer food producing industry (spent grain, potato peels, dry bakery, and biscuits products).

Step 2. If the feed ingredient is not a zero-allocation product, the method of economic allocation should be specified (see chapter 3.10.5.5).

A simplified input/ output analysis approach shall be used for processes where the differences in environmental impact of the post processing stage (e.g. drying) after splitting the input material are not very significant. Such processes are, for instance, the crushing of oil seeds, dry milling of grains, rendering of animal and fish products and other similar situations. At all other processing practices, a detailed approach shall be applied where the relative value of the products at the point of splitting is determined and the after processing (e.g. drying) is attributed to the specific co-product.

Specific and semi specific approach: Prices used for allocation shall be representative for the region in scope and shall be the average prices for a recent 3 years-period. Taxes, transport, insurance costs etc. should not be included in the price. Take notice that the absolute prices are not relevant, but the relative price difference between co-products are. It is important to use complete and consistent data for the range of co-products. Incomplete data from diverse sources may lead to incorrect results.

Default approach: In the default approach the allocation factors in Annex 5 should be used, as per LEAP Guidelines.

3.12.2 Processes that generate animal co-products used for rendering and fat melting

Most of the animal products used for rendering come from the slaughtering operation. This section describes the slaughtering of land animals and the rendering of part of the animal into feed ingredients.

3.12.2.1 Data collection

Slaughtering is the operation where animals are killed and divided in several parts (co-products) destined for either human consumption or other purposes. One of the main markets of clean slaughter co-products is feed.

Table 17 gives an overview of the inputs and outputs to be included or excluded.

Included	Excluded
• Animal species • Input: Output mass balance of animal (co) products • Allocation data (3.12.2.2) • Fuels use • Heat/ Electricity use • Auxiliary materials	• Depreciation of housing system

Table 17 Necessary activity data for the slaughterhouse operation

The default data for the slaughterhouse are available for bovine, porcine and chicken (for poultry). The default data make no distinction between beef and dairy animals at the slaughterhouse, with regards to mass fractions.

For branded, regional, and sectoral data a semi specific approach is allowed[4]. This means that default animal processing data available in the background database (Annex 6) may be used. These might be replaced by better more representative data if deemed necessary.

The implemented approach shall be specified in the meta data. The more specific the approach the better the data quality rating.

3.12.2.2 Allocation to co-products

Prices needed for economic allocation shall be representative for the region in scope and shall be average prices for a recent 3 year-period. Taxes, transport and insurance should not be included in the price.

3.13 Feed additives

In the GFLI database there are production data available for a mineral premix and a vitamin premix.

FAO LEAP (Livestock Environmental Assessment and Performance Partnership (FAO LEAP), 2020) have published their guidelines on feed additives, including production processes. This publication shall be used for generating feed additives datasets.

If available, further requirements on developing specific datasets can be added in this methodology.

4 The reason for this is twofold: 1) the allocation at slaughterhouse is very determining for the impact at farming and 2) specific farm data are for slaughterhouses currently not available.

4 References

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Annex 1 Current coverage of GFLI datasets

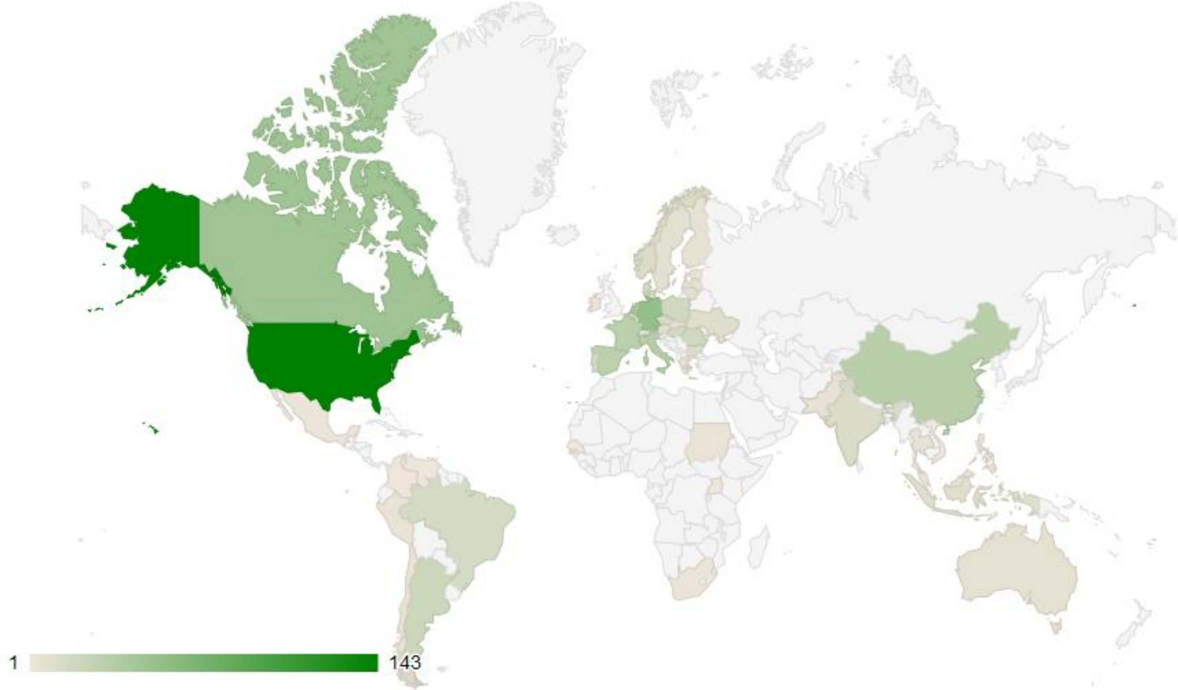

Figure 3: Amount of datasets per country in the GFLI database

Figure 3 illustrates for which countries most feed ingredients exist within the GFLI database. These feed ingredients could be either cultivated or processed products.

Annex 2 List of Impact factors feed ingredients names and DQR rating

The current list of datasets, including DQR and meta data information can be accessed at www.globalfeedlca.org/.... (insert final link).

Annex 3 DQR method

Annex 3.1 Data quality system and indicators

The DQR for feed ingredients is measured based on 4 aspects:

- Precision
- Time representativeness
- Technological representativeness
- Geographical representativeness

To evaluate the DQR a division needs to be made in type of data and how they are interrelated. Moreover, the data quality shall be determined on a cradle to gate process considering the contribution of data points to the overall environmental impact.

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

Data type	DQR criterion
Activity data	Precision: P
	Time Representativeness: TiR
	Technology Representativeness: TeR
	Geographical Representativeness: GeR
Background data	Time Representativeness: TiR
	Technology Representativeness: TeR

Table 18 DQR criteria used in connection to activity data and background data for production and combustion/conversion

The scoring of the DQR is determined based on a rating system derived from the DQR system applied in the PEF Table 18 gives an overview of the criteria for the rating.

	Activity data				Production of goods		Combustion/Conversion of goods	
	P	**TiR**	**TeR**	**GeR**	**Tir**	**Ter**	**Tir**	**Ter**
1	Measured/ calculated and verified	Data (at collection) is maximum 2 years older than the "reference year" of the GFLI database version	Technology of source data is the same as described in the title and meta data of the GFLI dataset.	Geography of source data is the same as geography stated in the "location" indicated in the meta data of the GFLI dataset	Reference year of the source data is maximum 2 year older than the reference year of the GFLI database version	Technology of source data is the same as described in the title and meta data of the GFLI dataset.	Reference year of source data is maximum 2 year older than the reference year of the GFLI database version	Technology of source data is the same as described in the title and meta data of the GFLI dataset.
2	Measured/ calculated/ literature and plausibility checked by reviewer	Data (at collection date) is maximum 4 years older than the "reference year" of the GFLI database version.	Technology of source data is very similar as to what is described in the title and meta data. (use of generic technology data instead of modelling all the single plants.)	Geography of source data is representative for the geography stated in the "location" indicated in the meta data	Reference year of source data is maximum 4 years older than the reference year of the GFLI database version	Technology of source data is very similar to what is described in the title and meta data. (use of generic technology data instead of modelling all the single plants.)	Reference year of the used dataset is maximum 4 years older than the reference year of the GFLI database version	Technology of source data is very similar to what is described in the title and meta data (use of generic technologies' data instead of modelling all the single plants).
3	Measured/ calculated/ literature and plausibility not checked by reviewer OR Qualified estimate based on calculations plausibility checked by reviewer	Data (at collection date) can be maximum 6 years older than the "reference year" of the GFLI database version.	Technology of source data is similar to what is described in the title and meta data but merits improvements. Some of the relevant processes are not modelled with specific data but using proxies.	Geography of source data is sufficiently representative for the geography stated in the "location" indicated in the meta data. E.g. the represented country differs but has a very similar electricity grid mix profile.	Reference year of the source data is maximum 6 years older than the reference year of the GFLI database version	Technology of source data is similar to what is described in the title and meta data but merits improvements. Some of the relevant processes are not modelled with specific data but using proxies.	Reference year of the source data is maximum 6 years older than the reference year of the GFLI database version	Technology of source data is similar to what is described in the title and meta data but merits improvements. Some of the relevant processes are not modelled with specific data but using proxies.

	Activity data				Production of goods		Combustion/Conversion of goods	
	P	**TiR**	**TeR**	**GeR**	**Tir**	**Ter**	**Tir**	**Ter**
4	Qualified estimate based on calculations. plausibility not checked by reviewer	Data (at collection date) can be maximum 8 years older than the "reference year" of the GFLI database version.	Technology of source data is different from what is described in the title and meta data. Requires major improvements.	The included dataset is only partly representative for the geography stated in the “location” indicated in the meta data. E.g. the represented country differs and has a substantially different electricity grid mix profile	Reference year of the source data is maximum 8 years older than the reference year of the GFLI database version	Technology aspects are different from what is described in the title and meta data. Requires major improvements.	Reference year of the source data is maximum 8 years older than the reference year of the GFLI database version	Technology aspects are different from what is described in the title and meta data. Requires major improvements.
5	Rough estimate with known deficits	Data (at collection date) can be maximum 10 years older than the "reference year" of the GFLI database version.	Technology aspects are completely different from what is described in the title and meta data. Substantial improvement is necessary	The processes included in the dataset are not representative for the geography stated in the ““location” indicated in the meta data.	Reference year of the source data is maximum 10 years older than the reference year of the GFLI database version	Technology aspects are completely different from what is described in the title and meta data. Substantial improvement is necessary	Reference year of the source data is maximum 10 years older than the reference year of the GFLI database version	Technology aspects are completely different from what is described in the title and meta data. Substantial improvement is necessary

Table 19 DQR criteria matrix

Annex 3.2 Data quality of agricultural processes
The approach for agriculture is closely related to how LCI data are generated for cultivation. The DQR of cultivation as a cradle to gate process can be defined as a function of the DQR of background data (production of goods & combustion of fuels) activity data and modelling elementary flows. We only consider the DQR of the activity data in combination with its background data and not the quality of modelling (Figure A- 2).

Figure A- 2 shows the list of activity (foreground and background) data to be evaluated.

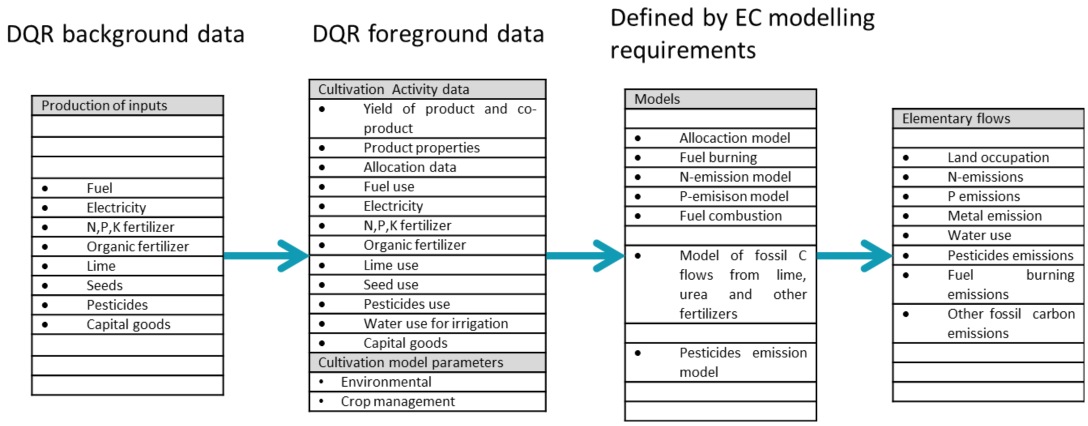

Figure A- 2 Basic scheme to evaluate the DQR of agricultural processes

Activity data for agriculture can be split into:

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

So, the environmental impact of cultivation can be written as follows:

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

Table 20 gives an overview of activity data and how the DQR is calculated.

Abbr	Name	Environmental impact	DQR
Fu	Fuel use [kg/l per ha]	Quantity in combination with production and combustion determines total impact. Production data come from EC T&E dataset. Combustion in agricultural machinery comes from AFP/AGB datasets.	Mathematical average of: 1. Production (Ter, Tir) 2. Use quantity (Ter.Tir. Gr. P) 3. Combustion data (Ter. Tir)
Eu	Electricity use [kwh/ha]	Quantity times production data (country specific)	Mathematical average of: 1. Production (Ter, Tir) 2. Use quantity (Ter.Tir. Gr. P)
F	Fertilizer use [kg product/ha]	Quantity times production data (AFP data sets and ELCD datasets)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
Fo	Organic fertilizer use [kg product/ha]	Quantity times production data (AFP data set)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
L	Lime use [kg CACO3/ha]	Quantity times production data (ELCD data set)	Mathematical average of: 1. Production (Ter.Tir)

Abbr	Name	Environmental impact	DQR
			2. Use quantity (Ter.Tir. Gr. P)
Su	Seed use	Quantity times production data (AFP)	Mathematical average of: 3. Production (Ter.Tir) 1. Use quantity (Ter.Tir. Gr. P)
Pu	Pesticides use	Quantity times production data (AFP)	Mathematical average of: 3. Production (Ter.Tir) 1. Use quantity (Ter.Tir. Gr. P)
Wu	Water use	Quantity	1. Use quantity
CG	Capital Goods depreciation	Quantity times production data (AFP)	Mathematical average of: 1. Production (Ter.Tir) 2. Use quantity (Ter.Tir. Gr. P)
Yield	Yield [kg/ha]	Quantity	Quantity
Allocation data	Mass* value Crop rotation	Allocation fractions derived from several data	Quantity

Table 20 Activity data mentioned in the Formula and how they relate to environmental impact and DQR

To determine the relevance of the activity data amongst each other and relative to yield and allocation a contribution analysis has been conducted for four main crops with datasets of which we know they are relatively complete: wheat UK; Soy BR. Maize FR and Rapeseed DE. The impact of allocation has been set on default on 2.5% (allocation involves co-product allocation and crop rotation allocation). The impact of yield is set equal to land occupation plus the impact of crop residues and is on average 12.5%.

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

Table 21 Contribution of environmental impacts related to activity data and connected production and combustion

The average contribution of activity data of these four crops shall be applied for all crops as an average weight factor for DQR contribution. These results provide an accurate estimate of the relevant importance of the lifecycle impact related to the activity data in this case.

Annex 3.3 Data quality of processing agricultural products
The environmental impact of processing of a crop is determined by 9 activity data of which 4 data points can be seen as scaling or context data such as the mass balance, allocation data, crop mix and transport modalities mix. The other activity data, such as use of crops, energy, water, and other raw materials are directly related to the type of crop extraction/splitting technology.

Activity data	Relation to elementary flows and impact
Mass balance	Scales and divides over co-products
Allocation data	Divides over co-products
Crop mix	Determines which crops and their impacts are considered and scales the relative impact of contribution of crops
Transport modalities mix	Determines the environmental intensity of transport
Production of crops	Quantity and Connection to background data
Transport	Quantity and Connection to background data
Fuel use	Quantity and Connection to background data
Electricity use	Quantity and Connection to background data
Water use	Quantity and Connection to background data
Other raw materials use	Quantity and Connection to background data

Table 22 Activity data of crop processing

Mass balance data of crop processing can vary due to the composition of the raw materials and technology parameters. For instance, the mass balance of dry milling is dependent on the grain constitution and the average amount of grinding runs. Both the composition of the grain and the amount of grinding runs can vary over time. The composition of grains relates to climate conditions and the number of runs relates to market conditions. The information on mass balances is often collected as a specific data point and separately maintained from other data points such as energy use.

Allocation data points are prices or energy values by which the masses of co-products are multiplied. Energy content values can vary in relation to the composition of the incoming crops and the technology parameters. Prices vary on top of that in relation to market conditions. Prices of co-products are also dependent on the location of production. The bigger the distance to international harbors and export markets the lower the price for the co-product at location of production. Allocation prices are therefore standardized and reflect an average situation relevant for the EU market. Prices for economic allocation need to be updated regularly. The allocation data used are from the (FAO LEAP, 2015a) and refer to a period of 2008-2012.

Both the mass balance and the price determine the amount of elementary flows assigned to a certain co-product.

Crop mixes and transport modality mixes are also not technology dependent but defined by the location of processing and the market of supply of crops. Some processing facilities are quite nearby located to the crop. This is mostly the case when the crop is voluminous or contains considerable water amounts so that transport is expensive. Examples are sugar beets, cane, potatoes, and other crops such as seeds, beans and grains can be transported long distances for processing. The data of origin of crops are important due to the variability environmental impacts of crops. These data are derived by analysis of production, import and export statistics. This also holds for the scenarios of transport distances and transport modalities. The baseline approach is a statistical analysis. For several processes, more accurate data can be collected from country statistics, literature, or business information.

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

Table 23 Average contribution of environmental impacts of processing activity data and connected production and combustion data

Annex 3.4 Data quality of other processes

The DQR of the production of animal-based products is based on the same methodology as for processed crops. Where the following activity data and its production processes are evaluated.

Activity data	Relation to elementary flows and impact
Mass balance	Scales and divides over co-products
Allocation data	Divides over co-products
Origin mix of animal raw materials	Defines relative impact of animal production/ fishing
Transport modalities mix	Determines the environmental intensity of transport
Production of animal products (fishing included)	Quantity and Connection to background data
Transport	Quantity and Connection to background data
Fuel use	Quantity and Connection to background data
Electricity use	Quantity and Connection to background data
Water use (if relevant)	Quantity and Connection to background data
Other raw materials use (if relevant)	Quantity and Connection to background data

Table 24 Activity data of animal processing

Annex 4 Default allocation factors

Process stage	Product	Input	In/out (kg/kg)	Economic allocation fraction	Mass allocation fraction	Gross energy allocation fraction
Cultivation	Barley / Oats	harvested plant	1.67	75%	60%	58%
Cultivation	Barley straw / Oats straw	harvested plant	2.50	25%	40%	42%
Cultivation	Wheat	harvested plant	1.56	79%	64%	64%
Cultivation	Wheat straw	harvested plant	2.78	21%	36%	36%
Dry milling	Wheat germ	Wheat	50.17	3.2%	2.0%	2.4%
Dry milling	Wheat middlings & feed	Wheat	8.03	6.6%	12.5%	10.8%
Dry milling	Wheat bran	Wheat	8.36	6.3%	12.0%	13.8%
Dry milling	Wheat flour	Wheat	1.36	83.9%	73.6%	73.1%
Dry milling	Rice bran	Rice	9.69	3.3%	10.3%	12.1%
Dry milling	Rice husk	Rice	4.85	1.3%	20.6%	16.0%
Dry milling	White rice	Rice	1.45	95.4%	69.0%	71.9%
Wet milling	Wheat bran	Wheat	5.56	8.2%	18.0%	10.9%
Wet milling	Wheat gluten feed	Wheat	12.54	5.0%	8.0%	11.2%
Wet milling	Wheat gluten meal	Wheat	9.96	29.0%	10.0%	9.8%
Wet milling	Wheat starch	Wheat	1.85	54.4%	54.0%	62.4%
Wet milling	Wheat starch slurry	Wheat	10.00	3.4%	10.0%	5.7%
Wet milling	Potato juice concentrated	Potato	8.54	85.7%	11.7%	73.4%
Wet milling	Potato protein	Potato	17.93	1.0%	5.6%	9.8%
Wet milling	Potato pulp pressed	Potato	11.17	11.5%	8.9%	7.6%
Wet milling	Potato starch dried	Potato	1.36	1.8%	73.8%	9.3%
Crushing (solvent)	Crude soy bean oil	Soy beans	5.11	41.5%	19.6%	39.3%
Crushing (solvent)	Soy bean hulls	Soy beans	13.11	2.9%	7.6%	4.7%
Crushing (solvent)	Soy bean meal (no added hulls)	Soy beans	1.37	55.7%	72.8%	56.0%
Crushing (solvent)	Soy bean meal (hulls added)	Soy beans	1.24	58.5%	80.4%	60.7%
Crushing (cold pressing)	Crude soybean oil	Soy beans	6.22	34.1%	16.1%	29.0%
Crushing (cold pressing)	Soybean expeller	Soy beans	1.19	65.9%	83.9%	71.0%
Crushing (solvent)	Rapeseed meal	Rape seed	1.78	23.9%	56.3%	35.3%
Crushing (solvent)	Crude rapeseed oil	Rape seed	2.29	76.1%	43.7%	64.7%
Crushing (cold pressing)	Rapeseed expeller	Rape seed	1.51	31.8%	66.2%	47.2%
Crushing (cold pressing)	Crude rapeseed oil	Rape seed	2.96	68.2%	33.8%	52.8%
Crushing (cold pressing)	Palm kernels	Palm Fruit Bunches	4.88	13.7%	20.5%	15.4%
Crushing (cold pressing)	Crude palm oil	Palm Fruit Bunches	1.26	86.3%	79.5%	84.6%
Crushing (cold pressing)	Crude palm kern oil	Palm kernels	1.99	89.8%	50.2%	71.4%
Crushing (cold pressing)	Palm kernel expeller	Palm kernels	2.01	10.2%	49.8%	28.6%
Rendering	Food grade fat	Food grade animal material	2.47	73.0%	40.5%	62.0%
Rendering	Greaves meal	Food grade animal material	1.68	27.0%	59.5%	38.0%
Rendering	Fish meal	Landed industry fish	1.23	87.5%	81.5%	67%

Rendering	Fish oil	Landed industry fish	5.40	12.5%	18.5%	33%

Table 25 Default allocation factors (FAO LEAP, 2015a)

Annex 5 Default modelling of agriculture

Annex 5.1 Start material

In case the amount of start material is not reported, crop specific defaults will be used to include the amount of start material and its impact. The amount of start material is derived from FAO statistics based on 3 or 5 year-average of seed use globally divided by the 3 or 5 year-average of agricultural area of that specific crop. An overview of the quantified average seed use for the most common feed crops is shown the Table 26 below.

Crop	Start material (kg/ha)
Barley	172.3
Broad bean	88.3
Groundnuts	73.1
Linseed	36.9
Lupins	62.8
Oats	265.9
Peas	139.7
Rye	235.1
Soybeans	65.4
Sunflower seed	27.1
Wheat	152.8

Table 26 Global average seed input for common feed crops

Annex 5.2 Pesticides

Pesticide emissions shall be modelled as specific active ingredients. The USEtox life cycle impact assessment method has a build in multimedia fate model which simulates the fate of the pesticides starting from the different emission compartments. Therefore, default emission fractions to environmental emission compartments are needed in the LCI modelling (Rosenbaum et al., 2015). As temporary approach, the pesticides applied on the field shall be modelled as 90% emitted to the agricultural soil compartment, 9% emitted to air and 1% emitted to water (based on expert judgement due to current limitations[5]). More specific data might be used if available.

A robust model to assess the link between the amount applied on the field and the amount ending up in the emission compartment is still missing today. The PESTLCI model might fill in this gap in the future but is currently still under testing.

Annex 5.3 Fertilizers

Fertilizer (and manure) emissions shall be differentiated per fertilizer type and cover as a minimum:

- NH3, to air (from N-fertilizer application)
- N2O, to air (direct and indirect) (from N-fertilizer application)
- CO2, to air (from lime, urea, and urea-compounds application)
- NO3, to water unspecified (leaching from N-fertilizer application)
- PO4, to water unspecified or freshwater (leaching and run-off of soluble phosphate from P-fertilizer application)
- P, to water unspecified or freshwater (soil particles containing phosphorous, from P-fertilizer application).

5 Several databases consider a 100% emitted to soil out of simplification (e.g. Agribalyse and Ecoinvent). It is recognized that emissions to freshwater and air do occur. However, emission fractions vary significantly depending on the type of pesticide, the geographical location, time of application and application technique (ranging from 0% to 100%). Especially the % emitted to water can be strongly debated, however, overall, it seems that 1% indicates a reasonable average (e.g. WUR-Alterra 2016: Emissies landbouwbestrijdingsmiddelen). Please note that these are temporary values until future modelling fills this gap.

The impact assessment model for freshwater eutrophication should start (i) when P leaves the agricultural field (run off) or (ii) from manure or fertilizer application on agricultural field. Within LCI modelling, the agricultural field (soil) is often seen as belonging to the technosphere and thus included in the LCI model. This aligns with approach (i) where the impact assessment model starts after run-off, i.e. when P leaves the agricultural field. Therefore, within the EF context, the LCI should be modelled as the amount of P emitted to water after run-off and the emission compartment 'water' shall be used. When this amount is not available, the LCI may be modelled as the amount of P applied on the agricultural field (through manure or fertilizers) and the emission compartment 'soil' shall be used. In this case, the run-off from soil to water is part of the impact assessment method and included in the CF for soil.

The impact assessment marine Eutrophication starts after N leaves the field. Therefore, the amount of emissions ending up in the different emission compartments per amount of fertilizers applied on the field shall be modelled within the LCI. Nitrogen emissions shall be calculated from Nitrogen applications of the farmer on the field and excluding external sources (e.g. rain deposition). To avoid strong inconsistencies among different PEFCRs, within the EF context it is decided to fix a few emission factors by following a simplified approach. For nitrogen-based fertilizers, the Tier 1 emissions factors of IPCC 2006 (Table 27) should be used. Note that the values provided shall not be used to compare different types of synthetic fertilizers. More detailed modelling shall be used for that. In case better data is available, a more comprehensive Nitrogen field model can be used by the PEFCR, provided (i) it covers at least the emissions requested above, (ii) N shall be balanced in inputs and outputs and (iii) it shall be described in a transparent way.

Emission	Compartment	Value to be applied
N_2O (synthetic fertilizer and manure; direct and indirect)	Air	0.022 kg N_2O/ kg N fertilizer applied
NH_3 (synthetic fertilizer)	Air	kg NH_3= kg N * FracGASF= 1*0.1* (17/14)= 0.12 kg NH_3/ kg N fertilizer applied
NH_3 (manure)	Air	kg NH_3= kg N*FracGASF= 1*0.2* (17/14)= 0.24 kg NH_3/ kg N manure applied
NO_{3^-} (synthetic fertilizer and manure)	Water	kg NO_{3^-} = kg N*FracLEACH = 1*0.3*(62/14) = 1.33 kg NO_{3^-} / kg N applied

Table 27 Tier 1 emissions factor of IPCC 2006 (modified)

FracGASF = Fraction of N-fertilizer applied that volatilizes as NH3.
FracLEACH = Fraction of N-fertilizer applied that is lost through leaching as NO3-.

It is recognized that the above nitrogen field model has its limitations and shall be improved in the future. Therefore, any PEFCR developed within the EF transition phase (2018-2020) and which has agricultural modelling in scope shall test (as minimum) the following alternative approach:

The N-balance is calculated using the parameters in Table 28 and the formula below. The total NO_3-N emission to water is considered a variable and its total inventory shall be calculated as:

“Total NO_3-N emission to water” = “NO_3- base loss” + “additional NO_3-N emissions to water”, with

“Additional NO_3-N emissions to water” = “N input with all fertilizers” + “N_2 fixation by crop” – “N-removal with the harvest” – “NH_3 emissions to air” – “N_2O emissions to air” – “N_2 emissions to air” -“NO3- base loss”.

If in certain low-input schemes the value for “additional NO_3-N emissions to water” be negative, the value is to be set to “0”. Moreover, in such cases the absolute value of the calculated “additional NO3-N emissions to water” is to be inventoried as additional N-fertilizer input into the system, using the same combination of N-fertilizers as employed to the analyzed crop. This serves to avoid regarding fertility-depleting schemes by capturing the N-depletion by the analyzed crop that is assumed to lead to the need for additional fertilizer later on to keep the same soil fertility level.

Emission	Compartment	Value to be applied
NO^{3-} base loss (synthetic fertilizer and manure)	Water	kg NO^{3-} = kg N*FracLEACH = 1*0.1*(62/14) = 0.44 kg NO^{3-}/ kg N applied
N_2O (synthetic fertilizer and manure; direct and indirect)	Air	0.022 kg N_2O/ kg N fertilizer applied
NH_3 - Urea (synthetic fertilizer)	Air	kg NH_3 = kg N * FracGASF = 1*0.15* (17/14) = 0.18 kg NH_3/ kg N fertilizer applied
NH_3 - Ammonium nitrate (synthetic fertilizer)	Air	kg NH_3 = kg N * FracGASF = 1*0.1* (17/14) = 0.12 kg NH_3/ kg N fertilizer applied
NH_3 - others (synthetic fertilizer)	Air	kg NH_3 = kg N * FracGASF = 1*0.02* (17/14) = 0.024 kg NH_3/ kg N fertilizer applied
NH_3 (manure)	Air	kg NH_3 = kg N*FracGASF = 1*0.2* (17/14) = 0.24 kg NH_3/ kg N manure applied
N_2-fixation by crop		For crops with symbiotic N_2-fixation: the fixed amount is assumed to be identical to the N-content in the harvested crop
N_2	Air	0.09 kg N_2 / kg N applied

Table 28 Alternative approach to nitrogen modelling

FracGASF = Fraction of N-fertilizer applied that volatilizes as NH_3.
FracLEACH = Fraction of N-fertilizer applied that is lost through leaching as NO_3-.

Annex 5.4 Heavy metal emissions

Heavy metal emissions from field inputs shall be modelled as emission to soil and/or leaching or erosion to water. The inventory to water shall specify the oxidation state of the metal (e.g., Cr+3, Cr+6). As crops assimilate part of the heavy metal emissions during their cultivation clarification is needed on how to model crops that act as a sink. Two different modelling approaches are allowed:

- The final fate of the heavy metals elementary flows are not further considered within the system boundary: the inventory does not account for the final emissions of the heavy metals and therefore shall not account for the uptake of heavy metals by the crop. For example, heavy metals in agricultural crops cultivated for human consumption end up in the plant. Within the EF context human consumption is not modelled, the final fate is not further modelled and the plant acts as a heavy metal sink. Therefore, the uptake of heavy metals by the crop shall not be modelled.
- The final fate (emission compartment) of the heavy metal elementary flows is considered within the system boundary: the inventory does account for the final emissions (release) of the heavy metals in the environment and therefore shall also account for the uptake of heavy metals by the crop. For example, heavy metals in agricultural crops cultivated for feed will mainly end up in the animal digestion and used as manure back on the field where the metals are released in the environment and their impacts are captured by the impact assessment methods. Therefore, the inventory of the agricultural stage shall account for the uptake of heavy metals by the crop. A limited amount ends up in the animal (=sink), which may be neglected for simplification.

Annex 5.5 Default energy use for activities

The following activities are considered in determining the total energy requirements for cultivation in the default approach

Activity	Equipment	Diesel use (l/ha)	Comment
Tillage	Ploughing; reversible plough 1.6 m	27.5	Specify equipment and frequency tillage. Multiple equipment can be used for this task. By default, this is specified per crop and country tillage statistics.
	Disc harrow, double, 3 m	6.6	
	Rotating harrow, 3 m	11.2	
Sowing	Seeder, cam wheel seed drill 3 m	5.2	Specify equipment used for sowing. By default, one type of equipment is use per crop (type).
	Planting machine, direct from dumper 3 m;	13.4	
	Seeder, distance 50 cm; precision 6 m	4.8	
	Large scale dumper, 37 m^3, 8500kg	7.3	
Irrigation	Furrow		By default, only applied for rice cultivation (0.3 MJ/m3)
	Hose reel		By default, only applied for “small” farms (1.2 MJ/m3)
	Centre pivot		By default, only applied for “large” farms (0.6 MJ/m3)
Manure	Manure injection (40 m^3)	31.5	Specify type of equipment used for manure spreading. By default, injectors are used for pig manure and much spreader for poultry manure.
	Manure injector, vacuum tank 20 m^3	43.27	
	Manure muck spreader, 6 t/10 tons application	15.3	
Fertilizer	Centrifugal spreader> 18 m 1500 l	2.9	Specify frequency of activity. Defaults are per crop type (1-6 applications).
Lime	Centrifugal spreader> 18 m 1500 l	2.9	Specify frequency of activity. Default = 0.25
Pesticide application	Field sprayer of 2000/24 m	3.0	Specify frequency of activity. Defaults are per crop type (0.1 – 16).
Weeding	Field sprayer of 2000/24 m	3.0	Specify frequency of activity. Defaults are per crop type (1-6)
Harvesting	Combine harvester, self-propelled, 6 m	31.4	Specify which harvesting equipment is used. Possibly multiple equipment is used to do the task. By default, this is specified for each crop (type).
	Haulm topper, 3 m	19.1	
	Self-propelled harvester, 3m (sugar beet)	40	
	Forage Harvester, self-propelled, 3 m	9.2	
	Maize MKS; 6-row self-driving	25	
	Groundnut windrowing, lifter (harvesting A groundnuts)	10	
	Grassland Topper	3.8	
	Grassland cutting eq, 3M	15	
	Self-propelled bunker harvester, 1.5 m (potatoes)	57.3	

	Groundnut thresher and picker (harvesting B groundnuts)	100	
	Large baler; straw/silage presses (excluding drain)	13.4	
Transport to storage	Medium scale dumper, 19 m^3, 6500kg	7.3	Specify equipment used for transporting the product to storage. By default, one type of equipment is specified per crop (type).

Activity	Equipment	Electricity use (MJ/ton dried)	Comment
Storage of crops	Silo	74.74	By default, only applied for grains

Table 29 Default energy use for activities

Annex 6 Default background data

Source	Background datasets
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV BE S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV DE S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV EU-27 S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV FR S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV GB S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV HU S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV IE S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV NL S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV PL S System - Copied from ELCD
Energy	Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S System - Copied from ELCD
Energy	Heat, from resid. heating systems from NG, consumption mix, at consumer, temperature of 55°C EU-27 S System - Copied from ELCD
Energy	Process steam from heavy fuel oil, heat plant, consumption mix, at plant, MJ EU-27 S System - Copied from ELCD
Energy	Process steam from heavy fuel oil, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD
Energy	Process steam from natural gas, heat plant, consumption mix, at plant, MJ BE S System - Copied from ELCD
Energy	Process steam from natural gas, heat plant, consumption mix, at plant, MJ DE S System - Copied from ELCD
Energy	Process steam from natural gas, heat plant, consumption mix, at plant, MJ EU-27 S System - Copied from ELCD
Energy	Process steam from natural gas, heat plant, consumption mix, at plant, MJ FR S System - Copied from ELCD
Energy	Process steam from natural gas, heat plant, consumption mix, at plant, MJ NL S System - Copied from ELCD
Rail	Transport, freight train, electricity, bulk, 80%LF, flat terrain, default/GLO Economic
Rail	Transport, freight train, electricity, bulk, 80%LF, hilly terrain, default/GLO Economic
Rail	Transport, freight train, electricity, bulk, 80%LF, mountainous terrain, default/GLO Economic
Rail	Transport, freight train, diesel, bulk, 80%LF, flat terrain, default/GLO Economic
Rail	Transport, freight train, diesel, bulk, 80%LF, hilly terrain, default/GLO Economic
Rail	Transport, freight train, diesel, bulk, 80%LF, mountainous terrain, default/GLO Economic

Source	Background datasets
Ocean	Transport, sea ship, 50000 DWT, 80%LF, short, default/GLO Economic
Ocean	Transport, sea ship, 50000 DWT, 80%LF, middle, default/GLO Economic
Ocean	Transport, sea ship, 50000 DWT, 80%LF, long, default/GLO Economic
Ocean	Transport, sea ship, 60000 DWT, 100%LF, short, default/GLO Economic
Ocean	Transport, sea ship, 60000 DWT, 100%LF, middle, default/GLO Economic
Ocean	Transport, sea ship, 60000 DWT, 100%LF, long, default/GLO Economic
Ocean	Transport, sea ship, 80000 DWT, 80%LF, short, default/GLO Economic
Ocean	Transport, sea ship, 80000 DWT, 80%LF, middle, default/GLO Economic
Ocean	Transport, sea ship, 80000 DWT, 80%LF, long, default/GLO Economic
Barge	Transport, barge ship, bulk, 1350t, 80%LF, empty return/GLO Economic
Barge	Transport, barge ship, bulk, 5500t, 80%LF, empty return/GLO Economic
Barge	Transport, barge ship, bulk, 12000t, 80%LF, empty return/GLO Economic
Truck	Transport, truck >20t, EURO2, 50%LF, default/GLO Economic
Truck	Transport, truck >20t, EURO3, 50%LF, default/GLO Economic
Truck	Transport, truck >20t, EURO4, 50%LF, default/GLO Economic
Truck	Transport, truck >20t, EURO5, 50%LF, default/GLO Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/AR Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/BR Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/CA Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/MY Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/US Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/AU Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/ID Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/IN Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/PH Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/PK Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/RU Economic

Source	Background datasets
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/SD Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/UA Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/CN Economic
Energy	Electricity mix, AC, consumption mix, at consumer, < 1kV/VN Economic
Energy	Energy, from diesel burned in machinery/RER Economic
Fertilizer production	Ammonia, as 100% NH3 (NPK 82-0-0), at plant/RER Economic
Fertilizer production	Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), at plant/RER Economic
Fertilizer production	Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), at plant/RER Economic
Fertilizer production	Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant/RER Economic
Fertilizer production	Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at plant/RER Economic
Fertilizer production	Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at plant/RER Economic
Fertilizer production	Single superphosphate, as 35% Ca(H2PO4)2 (NPK 0-21-0), at plant/RER Economic
Fertilizer production	Potassium chloride (NPK 0-0-60), at plant/RER Economic
Fertilizer production	Potassium sulphate (NPK 0-0-50), Mannheim process, at plant/RER Economic
Fertilizer production	NPK compound (NPK 15-15-15), at plant/RER Economic
Fertilizer production	Liquid urea-ammonium nitrate solution (NPK 30-0-0), at plant/RER Economic
Fertilizer production	PK compound (NPK 0-22-22), at plant/RER Economic
Fertilizer production	Ammonium sulphate, as 100% (NH4)2SO4 (NPK 21-0-0), at plant/RER Economic
Fertilizer production	Lime fertilizer, at plant/RER Economic
Fertilizer production	Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at regional storehouse/RER Economic
Fertilizer production	Liquid urea-ammonium nitrate solution (NPK 30-0-0), at regional storehouse/RER Economic
Fertilizer production	NPK compound (NPK 15-15-15), at regional storehouse/RER Economic
Fertilizer production	Ammonia, as 100% NH3 (NPK 82-0-0), at regional storehouse/RER Economic
Fertilizer production	Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), at regional storehouse/RER Economic
Fertilizer production	Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), at regional storehouse/RER Economic
Fertilizer production	Ammonium sulphate, as 100% (NH4)2SO4 (NPK 21-0-0), at regional storehouse/RER Economic
Fertilizer production	Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at regional storehouse/RER Economic

Source	Background datasets
Fertilizer production	Single superphosphate, as 35% Ca(H2PO4)2 (NPK 0-21-0), at regional storehouse/RER Economic
Fertilizer production	Potassium chloride (NPK 0-0-60), at regional storehouse/RER Economic
Fertilizer production	Potassium sulphate (NPK 0-0-50), at regional storehouse/RER Economic
Fertilizer production	Lime fertilizer, at regional storehouse/RER Economic
Fertilizer production	Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at regional storehouse/RER Economic
Fertilizer production	PK compound (NPK 0-22-22), at regional storehouse/RER Economic
Pesticide production	2,4-D, at plant/RER Economic
Pesticide production	2-Methyl-4-chlorophenoxyacetic acid, at plant/RER Economic
Pesticide production	Alachlor, at plant/RER Economic
Pesticide production	Aliphatic organothiophosphate insecticides, at plant/RER Economic
Pesticide production	Anilide herbicides, at plant/RER Economic
Pesticide production	Aryloxyphenoxypropionic herbicides, at plant/RER Economic
Pesticide production	Atrazine, at plant/RER Economic
Pesticide production	Benomyl, at plant/RER Economic
Pesticide production	Bentazone, at plant/RER Economic
Pesticide production	Benzimidazole fungicides, at plant/RER Economic
Pesticide production	Captan, at plant/RER Economic
Pesticide production	Carbamate insecticides, at plant/RER Economic
Pesticide production	Carbaryl, at plant/RER Economic
Pesticide production	Carbofuran, at plant/RER Economic
Pesticide production	Chlordimeform, at plant/RER Economic
Pesticide production	Chloroacetanilide herbicides, at plant/RER Economic
Pesticide production	Chlorotriazine herbicides, at plant/RER Economic
Pesticide production	Chlorsulfuron, at plant/RER Economic
Pesticide production	Cyanazine, at plant/RER Economic
Pesticide production	Cypermethrin, at plant/RER Economic
Pesticide production	Dicamba, at plant/RER Economic

Source	Background datasets
Pesticide production	Dinitroaniline herbicides, at plant/RER Economic
Pesticide production	Dinitrophenol herbicides, at plant/RER Economic
Pesticide production	Dipropylthiocarbamic acid S-ethyl ester, at plant/RER Economic
Pesticide production	Diquat, at plant/RER Economic
Pesticide production	Dithiocarbamate fungicides, at plant/RER Economic
Pesticide production	Diuron, at plant/RER Economic
Pesticide production	Fluazifop-p-butyl, at plant/RER Economic
Pesticide production	Fluometuron, at plant/RER Economic
Pesticide production	Fungicide, at plant/RER Economic
Pesticide production	Glyphosate, at plant/RER Economic
Pesticide production	Herbicide, at plant/RER Economic
Pesticide production	Insecticide, at plant/RER Economic
Pesticide production	Lindane, at plant/RER Economic
Pesticide production	Linuron, at plant/RER Economic
Pesticide production	Malathion, at plant/RER Economic
Pesticide production	Maneb, at plant/RER Economic
Pesticide production	Metolachlor, at plant/RER Economic
Pesticide production	Organochlorine insecticides, at plant/RER Economic
Pesticide production	Organophosphorus herbicides, at plant/RER Economic
Pesticide production	Paraquat, at plant/RER Economic
Pesticide production	Parathion, at plant/RER Economic
Pesticide production	Parathion, methyl, at plant/RER Economic
Pesticide production	Phenoxyacetic herbicides, at plant/RER Economic
Pesticide production	Phenyl organothiophosphate insecticides, at plant/RER Economic
Pesticide production	Phenylurea herbicides, at plant/RER Economic
Pesticide production	Phorate, at plant/RER Economic
Pesticide production	Phthalimide fungicides, at plant/RER Economic

Source	Background datasets
Pesticide production	Plant growth regulator, at plant/RER Economic
Pesticide production	Polymeric dithiocarbamate fungicides, at plant/RER Economic
Pesticide production	Propachlor, at plant/RER Economic
Pesticide production	Propanil, at plant/RER Economic
Pesticide production	Pyrethroid ester insecticides, at plant/RER Economic
Pesticide production	Quaternary ammonium herbicides, at plant/RER Economic
Pesticide production	Tetradifon, at plant/RER Economic
Pesticide production	Thiocarbamate herbicides, at plant/RER Economic
Pesticide production	Triazinylsulfonylurea herbicides, at plant/RER Economic
Pesticide production	Trifluralin, at plant/RER Economic
Pesticide production	Unclassified herbicides, at plant/RER Economic
Capital goods	Basic infrastructure, at farm/GLO Economic
Capital goods	Silo, for grain storage, at farm/GLO Economic
Capital goods	Tractor, production, at plant/RER Economic

Table 30 Default background data

Annex 7 Transportation distances

Manure, fertilizer and pesticides are transported to the farm. The default transport requirements to the farm are a transportation distance of 30 km for manure and a transportation distance of 50 km for all other inputs like fertilizer and pesticides.

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

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

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

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

FR	NL	Rapeseed	Crop_to_Process	194	63	88	498
FR	NL	Sunflower seed	Crop_to_Mix	274	75	90	498
FR	NL	Triticale	Crop_to_Mix	274	75	90	498
Country A	**Country B**	**Base Product**	**Transport Moment**	**Lorry dist**	**Train dist**	**InlandShip dist**	**SeaShip dist**
FR	NL	Wheat	Crop_to_Mix	274	75	90	498
FR	NL	Wheat	Crop_to_Process	218	73	71	498
ID	ID	Coconut	Crop_to_Process	15	0	0.0	0
ID	ID	Oil palm fruit bunch	Crop_to_Process	15	0	0.0	0
ID	NL	Coconut	Process_to_Mix	456	2	19	15794
ID	NL	Oil palm fruit bunch	Process_to_Mix	456	2	19	15794
IE	IE	Barley	Crop_to_Mix	58	1	0.0	0
IE	IE	Barley	Crop_to_Process	58	1	0.0	0
IE	IE	Barley	Process_to_Mix	58	1	0.0	0
IE	IE	Wheat	Crop_to_Mix	58	1	0.0	0
IN	IE	Sugar cane	Process_to_Mix	58	1	0.0	11655
IN	IN	Coconut	Crop_to_Process	15	0	0.0	0
IN	IN	Sugar cane	Crop_to_Process	25	0	0.0	0
IN	NL	Coconut	Process_to_Mix	224	672	19	11655
IN	NL	Sugar cane	Process_to_Mix	224	2	19	11655
MY	MY	Oil palm fruit bunch	Crop_to_Process	15	0	0.0	0
MY	NL	Oil palm fruit bunch	Process_to_Mix	160	107	19	14975
NL	BE	Oat	Crop_to_Process	141	26	128	0
NL	BE	Wheat	Crop_to_Process	141	26	128	0
NL	NL	Animal by-product	Process_to_Mix	56	2	19	0
NL	NL	Brewers grains	Process_to_Mix	56	2	19	0
NL	NL	Fodder beet	Crop_to_Mix	56	2	19	0
NL	NL	Fodder beet	Crop_to_Process	56	2	19	0
NL	NL	Fodder beet	Process_to_Mix	56	2	19	0
NL	NL	Maize	Process_to_Mix	56	2	19	0

NL	NL	Milk	Crop_to_Process	93	0	0	0
NL	NL	Milk	Process_to_Mix	56	2	19	0
NL	NL	Oat	Process_to_Mix	56	2	19	0
Country A	**Country B**	**Base Product**	**Transport Moment**	**Lorry dist**	**Train dist**	**InlandShip dist**	**SeaShip dist**
NL	NL	Oat	Crop_to_Process	56	2	19	0
NL	NL	Oat	Crop_to_Mix	56	2	19	0
NL	NL	Rapeseed	Process_to_Mix	56	2	19	0
NL	NL	Rye	Process_to_Mix	56	2	19	0
NL	NL	Soybean	Process_to_Mix	56	2	19	0
NL	NL	Starch potato	Crop_to_Process	56	2	19	0
NL	NL	Starch potato	Process_to_Mix	56	2	19	0
NL	NL	Sugar beet	Crop_to_Process	56	2	19	0
NL	NL	Sugar beet	Process_to_Mix	56	2	19	0
NL	NL	Sugar beet	Crop_to_Mix	56	2	19	0
NL	NL	Triticale	Crop_to_Mix	56	2	19	0
NL	NL	Wheat	Crop_to_Mix	56	2	19	0
NL	NL	Wheat	Process_to_Mix	56	2	19	0
NL	NL	Wheat	Crop_to_Process	56	2	19	0
PH	NL	Coconut	Process_to_Mix	456	2	19	17811
PH	PH	Coconut	Crop_to_Process	15	0	0.0	0
PK	IE	Sugar cane	Process_to_Mix	58	1	0.0	10900
PK	NL	Sugar cane	Process_to_Mix	1075	2	19	11275
PK	PK	Sugar cane	Crop_to_Process	25	0	0.0	0
PL	BE	Rye	Crop_to_Process	697	305	12	230
PL	NL	Rye	Crop_to_Mix	689	280	30	207
PL	NL	Rye	Crop_to_Process	633	278	10	207
SD	NL	Sugar cane	Process_to_Mix	461	2	19	7439
SD	SD	Sugar cane	Crop_to_Process	25	0	0.0	0
TH	NL	Cassava	Process_to_Mix	363	2	19	16787

TH	TH	Cassava	Crop_to_Process	15	0	0.0	0
UA	NL	Sunflower seed	Process_to_Mix	56	2	19	6423
UA	NL	Sunflower seed	Crop_to_Mix	341	2	19	6423
Country A	**Country B**	**Base Product**	**Transport Moment**	**Lorry dist**	**Train dist**	**InlandShip dist**	**SeaShip dist**
UA	UA	Sunflower seed	Crop_to_Process	285	0	0.0	0
UK	BE	Wheat	Crop_to_Process	134	11	0.09	784
UK	IE	Barley	Crop_to_Mix	170	12	0.1	441
UK	IE	Barley	Process_to_Mix	86	1	0.0	441
UK	IE	Wheat	Crop_to_Mix	170	12	0.1	441
UK	NL	Wheat	Crop_to_Mix	183	14	19	684
UK	NL	Wheat	Crop_to_Process	128	11	0.1	684
UK	UK	Barley	Crop_to_Process	84	11	0.1	0
US	DE	Maize	Crop_to_Process	182	619	1019	7266
US	IE	Maize	Crop_to_Mix	240	619	1019	5700
US	IE	Oat	Crop_to_Mix	240	619	1019	5700
US	IE	Rapeseed	Process_to_Mix	58	1	0.0	5700
US	NL	Citrus	Process_to_Mix	56	2	19	6423
US	NL	Maize	Crop_to_Mix	238	621	1038	6365
US	NL	Maize	Crop_to_Process	182	619	1019	6365
US	NL	Maize	Crop_to_Mix	238	621	1038	6365
US	NL	Maize	Process_to_Mix	56	2	19	6365
US	NL	Sorghum	Crop_to_Mix	238	621	1038	6365
US	NL	Soybean	Crop_to_Process	182	619	1019	6365
US	NL	Soybean	Process_to_Mix	56	2	19	6365
US	NL	Soybean	Crop_to_Mix	238	621	1038	6365
US	NL	Sugar cane	Process_to_Mix	238	2	19	6365
US	US	Maize	Crop_to_Process	182	619	1019	0
US	US	Rapeseed	Crop_to_Process	182	619	1019	0
US	US	Sugar cane	Crop_to_Process	25	0	0.0	0

Table 31 Transport distances (in km) and transport mode split for crops and processed crop products

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