gfli

Global Metrics for Sustainable Feed

# GFLI methodology and project guidelines

**30 January 2023**

# Table of contents

# Definitions

| | |
|---|---|
| **GFLI Database** | All datasets that are available by GFLI |
| **Database** | A set of datasets within the context of the GFLI database |
| **Dataset** | Data of a feed ingredient regarding its environmental impact or data of background processes 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 plant 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 according to the rules of the PEF guidance document. These are also implemented in the Agri-footprint database which is the source of the default data for the GFLI database. |
| **Branded data** | LCI/A data for a feed ingredient marketed under a certain brand and owned by an entity, such as a company that produces ingredients or a standardization body |
| **Product Environmental Footprint (PEF)** guidelines | 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 database. It can be used for developing regional, sectoral, or branded datasets or to improve datasets and/or methodology.

The GFLI methodology is built on several international standards on product footprinting and follows the latest IPCC methodology for calculation of GHG emissions by countries in their National Inventory Reports. GFLI Methodology and Project Guidelines Version 2.0 is an update of the Methodology and Project Guidelines version 1.0 published in November 2020. In the last two years several changes in the underlying methodology occurred. These developments are implemented in this version of the guidelines. Some updates on GFLI's approach on branded data are presented, but are prone to change after the GFLI branded data pilot will be finalized in 2023.

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

## 1.2 Set-up of the document

Chapters 1 and 2 give an introduction of the Institute, its foundation and the form of data projects available. Chapter 3 describes the GFLI methodology for collecting GFLI compliant datasets, divided in subchapters with the various aspects of the methodology, such as the system boundary, modelling framework, and data sampling. References and annexes are attached in addition to chapter 3 for information on the current coverage of datasets in the GFLI database, default data factors, and background data.

## 1.3 Authors and review team

The update of the methodology version 2.0 was edited by Mike van Paassen, Hans Blonk (Blonk Sustainability) and Laura Nobel (Agribusiness Service); in collaboration with feedback garnered from the Scientific Advisory Council (SAC) and the Technical Management Committee (TMC).

## 1.4 Version and validity

| | |
|---|---|
| *Version no:* | *2.0* |
| *Publication:* | *January 2023* |
| *Valid until:* | *Next update* |

## 1.5 Pilot on branded data

The Technical Management Committee (TMC) and GFLI Secretariat have developed a methodology for collecting branded data in a standardized and transparent manner, which at this phase is tested to achieve consistently robust datasets. Deviating from this Methodology and Project Guidelines on sectoral/regional datasets, branded data requires more primary data (higher data quality rating) and data sampling sizes. The evaluation of the pilot phase may result in an altered final methodology or the omittance of branded data once finalized if the desired results are not met. The final version of the branded data methodology will be published in 2023.

The following ingredient types are currently included in the criteria for branded data: cultivated feed ingredients, processed plant based products, processed animal based products, fish and fish-based feeds, co-products and manufactured products (e.g., feed additives).

# 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 Assessment (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 facilitates 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 advises 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) was established in 2021. GFLI's Scientific Advisory Council is an external expert panel incorporated to help the GFLI Board of Directors and Technical Management Committee (TMC) address critical questions regarding the quality, safeguarding, and improvement of the database, and to provide feedback about how to improve the methodology and procedures that govern the maintenance and continual improvement of the database. The Council is made up of experts in life cycle assessment methodologies and environmental and animal nutrition fields, each possessing a range of regional and sectoral experience.

## 2.2 GFLI methodology

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

1. the FAO/LEAP (Livestock Environmental Assessment and Performance) guidelines, developed in a multi-stakeholder initiative that seeks to improve the environmental sustainability of the livestock sector through harmonized methods, metrics, and data.
2. The PEFCR development of the European Commission and several sector associations, including FEFAC (European Commission, 2020)
3. The IPCC guidelines for national greenhouse gas inventories (IPCC, 2019a).

The methodological requirements and guidance from documents developed in these frameworks are brought together so that the GFLI guidance can be used as a stand-alone 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 overarching project purposes are distinguished: database developments and modelling developments. Also, three types of projects are described:

- Regional projects
- Sectoral projects
- Branded projects

Database development projects may involve a first development of LCI datasets or an update of existing LCI datasets.

Modelling developments are about more detailed emission modeling of existing LCI datasets or databases and can only be carried out for regional and sectoral projects (Table *1*). Modelling updates, regarding general LCA methodology or emission modeling throughout the whole of the GFLI database, are to be approved by the GFLI Board of Directors.

*Table 1 Different types of GFLI projects*

| | 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 |

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 for EF 2.0 (Blonk et al., 2017) and EF 3.0 data (European Commission, 2020)
- Feed PEFCR 2018 (European Commission, 2018a)
- FAO/LEAP feed additives guidelines 2020 (FAO/LEAP, 2020)

The LEAP feed and feed additives guidelines were 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 harmonized methods, better metrics and data. The LEAP Guidelines explain and suggest how LCA studies can be best performed. They define best practices but leave room for interpretation by the LCA executor.

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 that LCI data of supply chains need to be collected and modelled.

The Feed PEF database methodology document sets the requirements on how to model datasets in a manner 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 in external communication.
- Allows for the use of more accurate background data for specific regional database development.
- Allows for the use of more accurate emission modelling for specific regional database development.
- 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 methods of the Environmental Footprint (EF3.0) methodology of the European Commission (European Commission, 2019; Fazio et al., 2018) and ReCiPe Midpoint Hierarchy method (Huijbregts et al., 2016).

## 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).

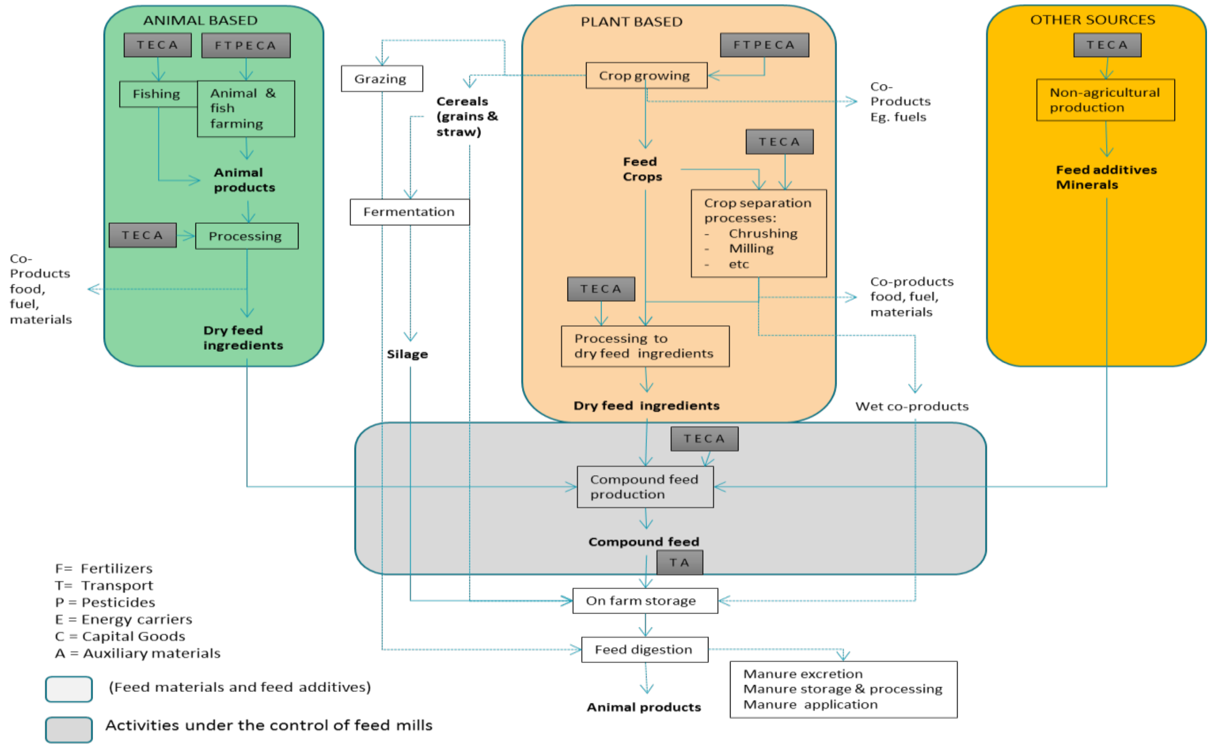


*Figure 1 Overview of the production chain of compound feed and other feed flows entering the farm*
Note that the term 'feed ingredient' also covers feed additives.

The full lifecycle of production of feed ingredients that can be used in compound feed is in scope (colored boxes). All data in the GFLI database relate to a reference unit of 1000 kg of product. Currently there are more than 300 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 **primary production (agriculture and fisheries), processing, and transport processes related to 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. The impact of the use of certain feed ingredients on animal performance at farm level (e.g., related to the use of feed additives) is also excluded. However, it is important to capture the positive impact of the use of those feed ingredients (e.g., by improving animal performance, by increasing digestibility of nutrients, or by maintaining animal in good health), when completing LCA for livestock production. See the FAO/LEAP guidelines on feed additives (FAO/LEAP, 2020) for more details to support feed additive LCA calculations.

**Depreciation of capital goods and machinery and use of consumables** are included for farming. They are excluded however, based on materiality, for processing of plants and animal products. The 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 data points 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 for energy carriers when the avoided product can be unambiguously determined. For example, when at processing of plant or animal-based products certain co-products are used for excess heat or electricity from combined heat and power production.

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

- Economic allocation: economic allocation measures the economic value of the main product produced and the by-products that are less economically valuable, for example soy is used to produce soy oil (main economic activity) with its by-product being soybean hulls and soybean meal.
- Mass allocation: mass allocation is the method to quantify masses entering and leaving a chemical or physical process. The mass-based allocation is done on the basis of the total, dry matter sum of the outputs.
- Energy allocation: energy content-based allocation is based on a caloric value in MJ per kg.

## 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 datasets for all three allocation methods according to the ReCiPe Midpoint Hierarchy method and the Environmental Footprint (EF) methodology of the European Commission (European Commission, 2020) impact assessments.

- The EF method includes impact categories: climate change and three subdivisions of climate change (global warming potential) through fossil, biogenic methane emissions, and land use (transformation), ozone depletion, ionizing radiation, photochemical ozone formation, respiratory inorganics, non-cancer human health effects, cancer human health effects, acidification, freshwater-, marine-, and terrestrial eutrophication, freshwater ecotoxicity, land use, water scarcity, resource use energy carriers, resource use (minerals and metals).
- ReCiPe includes the impact categories: global warming (incl. and excl. LUC), stratospheric ozone depletion, ionizing radiation, ozone formation (human health), fine particulate matter formation, ozone formation (terrestrial ecosystems), terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, land use, mineral resource scarcity, fossil resource scarcity, and 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 farm 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 on agricultural modelling according to the rules of the PEF guidance document (European Commission, 2018c). These are also implemented in the Agri-footprint database (http://www.agri-footprint.com/users/#methodology) which is the source of the default data (TIER 1 level) for the GFLI database.
- Regional specific modelling when data providers want to model their inventory data using a more detailed (higher TIER level) modelling approach. Alternative modelling approaches will be evaluated before implementation by the Technical Management Committee (TMC) and the Scientific Advisory Council (SAC) to ensure the quality. If the higher tier modelling approach can be considered as an improved default emission model, the model will be applied in the development of regional datasets.

GFLI LCI datasets shall be calculated based on the default modelling (TIER 1 level). If data are developed based on higher TIER level modelling, they shall be published separately until the modelling they use is applied as part of the default methodology.

### 3.6.2 Default GFLI data and use of alternative data sources

The default GFLI data for products and processes used at primary production, processing and transport originate either from the Agri-footprint database version 6.3 (Blonk et al., 2022) or from data collected during GFLI “data-in" projects. Which background data may be used is defined more specifically in sections 3.10, 3.11 and 3.12.

GFLI LCI datasets that are generated in data in projects can be adjusted default GFLI data to fit project-specific circumstances. They can request that GFLI provide a disaggregated and parameterized version of specific background data as listed in Annex 5. This will allow for the development of new feed ingredients and background data with an improved data quality.

## 3.7 Data sources in relation to type of project

The three subtypes of data-in projects require different types of data sources. For datasets of branded products, more primary and/or secondary improved data are needed than for regional or sectoral datasets[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).

*Table 2 Minimal requirements for deriving regional and sectoral datasets (SEC means secondary data, see further explanation below Table)*

| Stages | | Regional products | | | Sectoral products | | |
|---|---|---|---|---|---|---|---|
| | | **Plant based Crops/ fisheries** | **Processed products with 1 processing step** | **Processed products with multiple processing** | **Plant based crops / fisheries** | **Processed product with 1 processing step** | **Processed product with multiple processing** |
| **Cultivation/ fishing** | Inputs “activity data” | **SECIMPROVED** | SECDefault | SECDefault | **PRIMARY** | SECDefault | SECDefault |
| **Trans port** | Market mix & Logistics | | **SECIMPROVED** | SECDefault | | **SECIMPROVED** | SECDefault |
| **Animal farm** | Farm activity data | | **SECIMPROVED** | SECDefault | | **SECIMPROVED** | SECDefault |
| **Trans por** | Farm prod. mix & Logistics | | **SECIMPROVED** | SECDefault | | **SECIMPROVED** | **SECIMPROVED** |
| **Primary processing** | Processing activity data | | **SECIMPROVED** | SECDefault | | **PRIMARY** | **SECIMPROVED** |
| **Tran sport** | Product Mix & Logistics | | | **SECIMPROVED** | | | **SECIMPROVED** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Secondary processing** | Processing activity data | | | **SECIMPROVED** | | | **PRIMARY** |

Table 2 indicates the minimal requirements for deriving feed ingredient datasets in regional or sectoral data-in projects. Each processing step for regional and sectoral products shows which type of data is necessary for that specific data-in project. For cultivated products this only includes the steps for cultivation. For processed products it is separated into products that are typically produced in one processing step/facility and in two or more processing steps.

Regional datasets do not require primary data as a baseline, but it is encouraged to use the highest quality of secondary data that is available for the region in scope.

For sectoral datasets it is mandatory to use primary activity data for the last process step in the production chain. The process step before should use secondary improved data.

Below is an explanation of the terms in the table:

- PRIMARY: Refers to data from the operations which are under the control of the data-in provider, referring to the farming/fisheries or manufacturing process of the data-in provider.
- SECimproved: Secondary improved data and refers to data that are already collected in databases or other sources that are not used for the default (Agri-footprint) data and that are of higher quality and/or more representative.
- SECdefault: Default data based on the available Agri-footprint database.

Generating new datasets for ingredients that already exist in the GFLI database require higher data quality than the original data, either through secondary improved data or primary data.

The basic principle for branded data is to use as much primary data as possible and is needed for deriving accurate results. Therefore, the minimal requirements for primary data depend also on the contribution of the data points to the overall impact and their accessibility.

The minimal data requirements for regional and sectoral data are further elaborated in sections 3.10 to 3.12.

## 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 rating (DQR)

Data quality measurement is conducted based on the data quality matrix, developed in the EC feed database project. The overview of the full Data Quality Rating (DQR) matrix is portrayed in Annex 2. This information is gathered during the data collection process, and includes 4 Data Quality Indices (DQI) which are:

- Precision
- Time representativeness
- Technological representativeness
- Geographical representativeness

To evaluate the DQR, a division is made in type of data and how they are interrelated. A 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, electricity, and combustion of fuels or other chemical conversion during processing. This gives the following set of evaluation points (Table 3).

*Table 3 DQR criteria used in connection to activity data and background data for production and combustion/conversion*

| 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 |

When the DQR of a product becomes too high, therefore being insufficiently representative in the market, the product/dataset should be updated. GFLI follows the EC PEFCR guidelines, where accordingly a total DQR ***≤3.0*** for relevant processes in secondary data is desirable, with other processes needing a total DQR of ***≤4.0*** (European Commission, 2020). The DQR in the GFLI database will be updated every two years based on the TiR, with the current trajectory a dataset will lose relevancy in DQR measurements after four to six years.

## 3.10 Modelling of cultivated products

### 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).

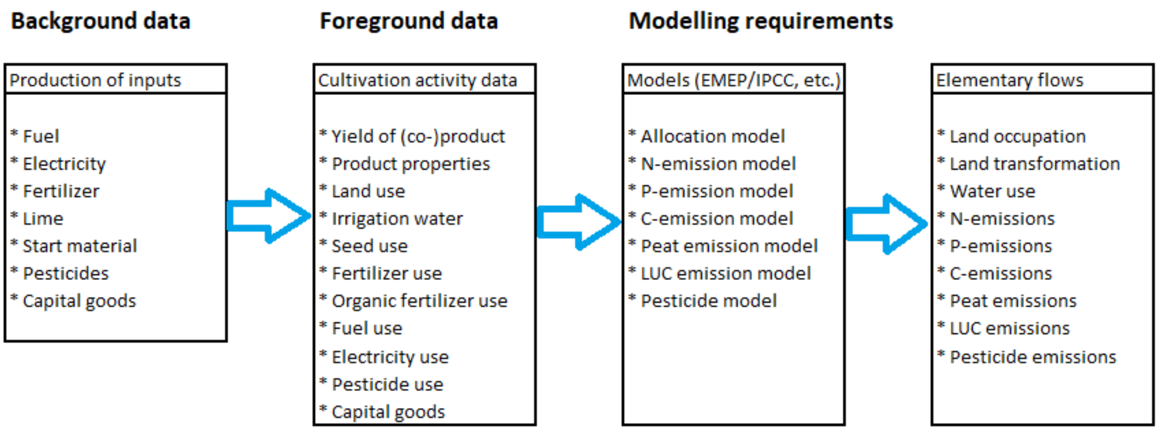


*Figure 2 Schematic overview of how elementary flow are modelled at cultivated products*

Depending on the type of emission model (TIER level) and way of allocation, additional information need 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 4 shows the activity data that needs to be included at cultivation.

*Table 4 Included and excluded activities and elementary flow in cultivation, processing of crops and other production (for italic included default background data may be used)*

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

Other consumables may be excluded 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 or animal farming (e.g. wind or solar power) are only accounted for, when used at that farm again.

Some activity data are more important than others. The italicized data points in Table *4* 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 4), transportation distances capital goods (Blonk et al., 2017) or packaging material of fertilizers and pesticides (Blonk et al., 2022).

### 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 5 gives an overview how the EC tender requirements are applied in the data collection process of the main data sources.

*Table 5 Implementation of the (steady state) average requirement in the source databases used for the GFLI database*

| 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.<br>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. |

### 3.10.4 Assigning inputs and outputs to crops and allocation of crop coproducts

Assigning in-and outputs for crops is relevant when in arable farming crop rotation is maintained, or multiple processes are present on the same farm. To assign the different activities and inputs to specific crops and co-products the LEAP feed guidelines (FAO/LEAP, 2015a, figure 7 on page 37) are followed. This is also relevant for the allocation of emissions towards the multiple co-products produced by harvested plants (such as seeds and straw). Table 6 shows how the different allocation topics are handled in the GFLI database.

*Table 6 Handling of allocation topics in the source databases*

| Allocation topic | GFLI Default approach | Alternative options |
|---|---|---|
| Activities related to crop rotation<br>• 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). | . |

### 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

There is a template available for data collection, which is made available for data-in providers. The template may be adjusted to fit the scope and purpose 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 2.

Per activity data point there are three approaches. These approaches affect the DQR of the dataset, specifically the Precision (P), Technical representativeness (TeR), Time representativeness (TiR) and Geographical representativeness (GeR) criteria of the DQR (see chapter 3.9 and annex 2). The possible approaches for data collection (referenced in Table 2):

- **Primary data** collection where as much as possible/needed primary data of processes are collected (on-farm or on-facility data)
- **Secondary GFLI default data** – default background data from Agri-footprint
- **Secondary improved data** where improved data sources are used compared to the default background data.

These approaches are elaborated for the activity data points required in the following subchapters.

Regional projects should collect at least secondary improved data for the most contributing activity data points at cultivation:

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

Sectoral projects should collect these primary data for cultivation for the most contributing activity data (Table 2).

Branded projects (e.g. cultivation according to a certification scheme) should collect primary data for all necessary activity data, retaining a DQR lower than 2 by having less than 30% of the impact of the end product coming from  secondary data.

#### 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 yield data should comply to the requirements on steady state, time frame and allocation as explained in the sections 3.10.3 and 3.10.4.

**Primary data:** are data based on recent farm records (available in e.g. farm data management systems or accountancy systems) or recent surveys that and are based on reliable validated data and represent the cultivation in scope.

**Secondary GFLI default data**: for crop yields are collected from FAOstat yield statistics (FAOstat, 2022) can be used. A 3- or 5-year yield average shall be used in line with the requirements set in chapter 3.10.3. In case a 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.

**Secondary improved data**: are based on well-established data sources representative for the region in scope by statistical institutions, governmental or research bodies and of better quality than FAO stat data to be explained in the meta data.

### 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 records or statistics.

**Primary data:** are based on recent farm records (available in e.g. farm data management systems or accountancy systems) or surveys that collect farm data and are based on reliable validated data and represent the cultivation in scope.

**Secondary GFLI default data** are estimates based on fixed percentages of above ground crop residue that is collected as straw for cereals, pulses and oilseeds, further described in AFP (Blonk et al., 2022).

**Secondary improved data**: can be based on measurements, statistics, reports, or any other reliable information from which the yield of co-products can be derived. Contrary to main products, there is usually little information on the yield of co-products in statistics and reports. The following can be considered as secondary improved data collection approach: derive yield of co-products from information on fractions of harvested above ground biomass or use straw-to-grain ratios. Examples of literature on straw-to-grain ratio of specific products (Copeland & Turley, 2008; Mcdonald, 2010; Searle & Bitnere, 2017). The data quality should be improved compared to the GFLI default data and must be clarified in the meta data.

### 3.10.5.3 Product properties data

Product properties concern chemical or physical aspects of feed ingredients which are relevant for calculating the overall feed nutritional data, and for allocation purposes and/or heavy metal calculations (see chapter 3.10.6). Table 7 shows the data that need to be collected for crops and co-products. There are three categories of data points distinguished:

- Shall, without this property data the dataset 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 GFLI defaults are used.

*Table 7 Data to be collected for crop (co)- products*

| | Unit | Primary data | Secondary improved data |
|---|---|---|---|
| **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 |

Differentiation of feed ingredients through nutritional values (e.g., crude protein, crude fiber) is currently not present in the database. Exceptions may occur where this data is relevant to mention, for example a high crude protein soybean (48%) or a low crude protein soybean (44%), barley/wheat with high or low specific weight, or if it is a raw ingredient that has been treated or protected to increase its nutritional profile. These may be added to the name of the product for data users.

### 3.10.5.4 N in crop residues

The quantification of nitrogen in crop residues is needed for the calculation of nitrous oxide and nitrate emissions, as shown in Section 3.10.6.

**Secondary GFLI default data:** nitrogen from crop residues is calculated using IPCC estimations of N added to soils from crop residues per crop(type) (IPCC, 2019). 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.

**Primary data and secondary improved data:** Actual measurements of N in crop residues is a constraint approach and usually lacking, in this case secondary improved data may be used. The amount of nitrogen from crop residues can be calculated using national or regional farm guidelines or publications. Also, the methodology developed for drafting the National Inventory Reports for IPCC climate impact monitoring is reliable source. In any case, the data quality should be improved compared to the GFLI default data and must be clarified in the meta data.

### 3.10.5.5 Allocation data for co-production

The GFLI database includes three allocation methods for which all three allocations data needs 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 content of products and co-products

**Primary data and secondary improved data**: Prices of products 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 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.

**Secondary GFLI default data**: In the default approach the allocation fractions in Annex 3 are used.

### 3.10.5.6 Energy use

Energy use involves all on-farm energy use related to the production and storage of the crop. This 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. Energy use at farming also includes the usage of fossil fuels as lubricant oils for tractors and machinery.

#### 3.10.5.6.1 Energy use during field operations

**Primary data:** data come from recent farm records (available in e.g. farm data management systems or accountancy systems) or surveys that collect farm data and are based on reliable validated data and represent the cultivation in scope. Another potential source could be using measured data for activities from for instance the machinery and equipment monitoring (can be a service of equipment suppliers).

**Secondary GFLI default data:** are based on an energy model for cultivation that has been developed in a cooperative project between Blonk Consultants and Wageningen University. 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 (See Annex 4).

**Secondary improved data:** are based on well-established data sources representative for the region in scope by statistical institutions, governmental or research bodies (representation to be explained in the meta data) estimating energy use based on frequency of activities related to energy use.

#### 3.10.5.6.2 Energy use during storage

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

**Secondary GFLI default data**: Energy use for storage is calculated using Eurostat data on humidity, safe storage conditions described in FAO and energy of 0.15 kWh electricity and 4.5 MJ natural gas per kg of water evaporated.

**Secondary improved data**: are based on well-established data sources representative for the region in scope by statistical institutions, governmental or research bodies (representation to be explained in the meta data). A potential allowed method is to calculate the energy inputs of water evaporation, where 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 is assumed to be 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).

The following tables (Table 8 and Table 9) give an overview of the different energy sources used during field operations and storage for which data need to be collected.

*Table 8 Energy use for cultivation at the farm. For lubricant oils defaults may be used*

| 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 storage*

| 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* |

** 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.

### 3.10.5.7 Fertilizer use (N, P, K)

Application of synthetic fertilizers to crops is crop specific and taking the application of organic fertilizers into account. The amounts of N, P, K uses needs to be translated to specific fertilizer types (Table 10) this can be done in multiple ways:

**Primary data:** fertilizer use include the quantities of N, P, K and the chemical compound as used and are based on recent farm records (available in e.g. farm data management systems or accountancy systems) or recent surveys that and 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 10. 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 the fertilizers by the GFLI database manager to ensure a sound linkage to background data. If required, corrections will be performed to match the nutrient quantity in the inventories to the quantity in the background data.

**Secondary GFLI default data**: NPK data collected according to Agri-footprint methodology are used to determine fertilizer use for crops. By combining the default NPK data with statistics from the International Fertilizer Association (IFA, 2017), amounts of specific fertilizer types are inventoried.

**Secondary improved data:** can be collected in several ways, by using representative national or (sub)regional surveys or by combining crop 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 crop-specific NPK information. 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. The inventoried NPK data needs to be matched to the fertilizers shown in the Table 10. For any method of data collection, the improved data quality compared to the GFLI default data needs to be substantiated in the meta data.

*Table 10 Available fertilizers in the GFLI database*

| 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), market mix | Kg product/ha |
| Ammonium nitrate, as 100% $(NH_4)(NO_3)$ (NPK 35-0-0), market mix | Kg product/ha |
| Ammonium sulphate, as 100% $(NH_4)2SO_4$ (NPK 21-0-0), market mix | Kg product/ha |
| Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix | 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), market mix | Kg product/ha |
| NPK compound (NPK 15-15-15), market mix | 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), market mix | Kg product/ha |
| Lime Fertilizer | Kg $CaCO_3$/ha |
| Dolomite | Kg $CaMg(CO_3)_2$/ha |

### 3.10.5.8 Organic fertilizer application

Organic fertilizers (manure and other sources such as animal meals or compost) 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.

**Primary data:** the use of organic fertilizer is based on recent measurements, farm records, accountant reports, or statistics and surveys that are based on 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. 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 based on the 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)

$$\textit{Total N from Organic Fertilizer}_{\textit{applied to the plot where crop A stands}} = NmOA + NcrA + aA/aT \times NoO$$

- 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)

**Secondary GFLI default data:** uses the methodology described in the report of Feedprint (Vellinga et al., 2013). It relies on statistical information of manure (FAO, 2021).

**Secondary improved data:** are more representative for the region or country in scope than FAO data. This involves for instance data that are collected by a public or industry body that monitors manure application in a certain country/region combined with 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 11). For any method of data collection, the improved data quality compared to the GFLI default data needs to be substantiated in the meta data.

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).

*Table 11 Overview of data requirements for organic fertilizer application for the different approaches*

| | 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 |

### 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.

**Primary data:** on application of $CaCO_3$ fertilizers 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.

**Secondary GFLI default data:** a default $CaCO_3$ use of 400 kg/hectare is applied for all agricultural crops, based on assumptions made in Feedprint (Vellinga et al., 2013).

**Secondary improved data:** can be collected in several ways. Allowed as secondary improved data is using statistics on lime and/or dolomite use within a specific region on arable crops divided by the amount of arable area within that specific area.

### 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:

**Primary data:** are farm and crop specific on the quantity of irrigation water applied to fields This data can be based on measurements, statistics, reports, or any other reliable information. Other blue water use related to the cultivation of the crop might be included as well.

**Secondary GFLI default data:** are based on the amount of irrigation water as defined in 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 $m^3$/ton of product (Mekonnen & Hoekstra, 2010). Combined with 5-year average FAO yields the blue water footprint is calculated in $m^3$/ha.
Not all of the applied irrigated water is actually consumed during cultivation of the crop. In GFLI, water requirement ratios are implemented to determine the actual water consumption of irrigation water. These ratios are county specific and originate from the ReCiPe Characterization report (Huijbregts et al., 2016)

**Secondary improved data**: 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. For any method of data collection, the improved data quality compared to the GFL default data needs to be substantiated in the meta data

#### 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:

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

**Secondary GFLI default data:** 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.

**Secondary improved data** can be collected from various reliable information sources on country or regional level. The data should be at least crop specific. For any method of data collection, the improved data quality compared to the GFLI default data needs to be substantiated in the meta data.

#### 3.10.5.12 Pesticides use

Pesticides data are often hard to collect, due to insufficient farm records and lack of detailed surveys or statistics. Since pesticides use is strongly influenced by legislation and regional plague risks, which can vary year by year, it is necessary to collect farm and/or country crop specific information.

**Primary data**: collect crop and region-specific farm data for pesticide use. The total amount of active ingredient of the pesticide(s) applied per hectare of cultivation should be provided, as well as the CAS-number of the active ingredient.

**Secondary GFLI data:** crop average pesticide data of available crops same crop-types are used as a proxy.

**Secondary improved data**: collect pesticide data from regional country crop specific representative sources. In many situations, expert judgement of agricultural advisory organizations is needed to complete statistics and surveys. In general, pesticides use information becomes of better quality when different data sources are combined. For example, combining expert judgement with national statistics on pesticides sales for agriculture and usage surveys. For any method of data collection, the improved data quality compared to the GFLI default data needs to be substantiated in the meta data.

#### 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 4. 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.

#### 3.10.6.1 Modelling of land use change/land transformation (emissions)

**Primary Data:** impacts related to land use change can be estimated by collecting data on the previous land use of the cultivated area 20 years ago and including specific carbon stock changes for the area in scope. The calculation of carbon emissions should follow the PAS 2050-1 methodology (as adopted in the PEF methodology and recommended method in the GHG protocol)l. Land use change impacts should be reported in kg $CO_2$, $CH_4$ and $N_2O$ per annual hectare cultivation.

**Secondary GFLI default data:** Land use change is estimated using the "Direct Land Use Change Assessment Tool version 2021" that is developed by Blonk Sustainability to conduct PAS 2050-1 (BSI, 2012) and PEF compliant LUC calculations. This tool provides a predefined way of calculating greenhouse gas (GHG) emissions from land use change when previous land use is known or unknown and based on FAO statistics and IPCC calculation rules, following the PAS 2050-1 methodology.

**Secondary improved data:** for land use change data involves the use of data sources that are more accurate than the default national conversion areas and carbon stocks used in the Direct Land Use Change Assessment Tool version 2021. In any case the improved data quality compared to the GFLI default data needs to be substantiated in the meta data.

#### 3.10.6.2 Emissions from drained peat soils

**Primary data:** are farm specific data on soil peat content combined with relevant country/regional emission modelling of $CO_2$ and $N_2O$ preferably compliant with National Inventory Reporting methodology. The emission factors should be crop and country specific and reported in kg $CO_2$, $CH_4$ and $N_2O$ per annual hectare cultivation.

**Secondary GFLI default data:** uses $CO_2$, $CH_4$ and $N_2O$ emission factors from the specific country National Inventory Report (NIR) 2019 submission (average of 2012-2017 data) combined with national data of specific crops. Details on this approach can be found in Annex 4.3.

**Secondary improved data:** involves the use of data sources that are more accurate than the default GFLI data used for peat oxidation for crop/country combinations. In any case the improved data quality compared to the GFL default data needs to be substantiated in the meta data.

### 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 5 gives an overview of background datasets.

## 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 12 gives an overview of the inputs and outputs to be included or excluded.

*Table 12 System boundaries for fisheries*

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

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 under development. In the current draft version of the PEFCR economic allocation is applied for landed fish by default. In the current GFLI database (default GFLI data) for fish meal and fish oil no allocation for fisheries needed to be applied because the complete landings of mackerel and anchovies and other industry fish were used for rendering. In future updates, further specification on processing fish meal from human grade fish trimmings shall be included.

For primary data collection in projects the marine fish PEFCR can be used as a reference document (currently available draft version 5 https://www.marinefishpefcr.eu/supporting-studies).

### 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 more detailed modeling of animal products.

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

*Table 13 System boundaries for animal husbandry*

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

The data for animal husbandry should be collected for a specific region and the animal products are used as input for processing. There are several approaches possible, for the collection of farm data:

**Primary data:** consists of representative farm data including all activity data points as mentioned in Table 13.

**Secondary GFLI default data:** 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.

**Secondary improved data:** is only needed for branded data. For sector- and region-specific products use of default farm data available in background databases is allowed.

In any case all assumptions shall be clearly specified in the meta data.

#### 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

Plant Crops and animal farm products can be processed into feed ingredients.

### 3.12.1 Modelling of processed plant-based products

Most of the processed feed ingredients are made of plant-based crops, split into different co-products in a processing facility. 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.
Processed animal-based products are also used as feed ingredients. There are several fat and protein products used as feed ingredient.

Processing to feed ingredients is mostly happening in large scale processing facilities where besides energy use there is limited input of other raw materials. In several cases processing aids are used 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 14 gives an overview of the inputs and outputs to be included or excluded.

*Table 14 System boundaries for processing of crops*

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

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 15 gives an overview of the processing technologies and auxiliary materials available in the GFLI database.

*Table 15 Overview of different processing techniques and auxiliary materials available in the GFLI database*

| Process | Auxiliary materials | Current source of activity data used in Agri-Footprint |
|---|---|---|
| Animal rendering | None | (van Zeist et al., 2012a) |
| Fish rendering | Sodium hydroxide<br>Formaldehyde<br>Ethanol<br>Sulfuric acid<br>Nitric acid<br>Hydrochloric acid | (van Zeist et al., 2012a)<br>(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)<br>(Schneider & Finkbeiner, 2013) |
| Oil refining | Bleaching earth<br>Phosphoric acid<br>Sulfuric acid<br>Active carbon<br>Sodium hydroxide | (van Zeist et al., 2012c)<br>(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) |

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

**Primary data:** data collection to be applied for branded product projects and sectoral projects which require primary data for all inputs:

- Mass balance and prices
- Cultivation data
- Crop mix of originating countries

- Transport (distance per transport means)
- Fuel 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 then be considered not relevant and not collected. This should be reported in the meta data.

**Secondary default GFLI data:** are collected as follows:
Mass balance and prices are derived from literature (see Table 15).

- 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 processing facility, default data on transportation distances and transportation modes are used (see Annex 6).
- Use of fuels, electricity, water, and auxiliary materials are derived from literature and connected to country-specific production data when available, otherwise global average datasets are used.

The implemented approach shall be specified in the meta data. The data quality rating will improve with the specificity of the approach.

**Secondary Improved data:** This approach can be used for sector- or region-specific data, which requires primary data collection for:

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

### 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 products, 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. For 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 post processing (e.g. drying) is attributed to the specific co-product.

**Primary and secondary improved data:** Prices used for allocation shall be representative for the region in scope and shall be the average prices for a recent 3-year 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 is relevant. 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.

**Secondary GFLI data:** In the default approach the allocation factors in Annex 3 are 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 into 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 16 gives an overview of the inputs and outputs to be included or excluded.

*Table 16 Necessary activity data for the slaughterhouse operation*

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

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 regard 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 5) 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

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. However, the following deviations shall also be considered for the introduction of feed additive datasets in the GFLI database.

### 3.13.1 Boundaries

As for any feed ingredient introduced in the GFLI database, the impact assessment of a feed additive is limited to the cradle to feed additive manufacturing site exit gate.

### 3.13.2 Functional Unit

The Functional Unit relates to the feed additives, as placed on the market, and is expressed as the weight or volume (for liquid feed additives) of the additive, as placed on the market.

Information indicating the concentration of active substance(s) in the feed additive shall be provided, if the quantity of feed additive, as placed on the market, incorporated in the feed or premix will depend on this concentration, to allow the evaluation of the impact of the feed additive during its use phase. As appropriate, representative information shall be included in the GFLI metadata.

### 3.13.3 Packaging

Considering the high variability of packages used for feed additives (from small bags to bulk) and the potential for different packaging proposed for a same feed additive by its supplier(s), the data sets, for inclusion in the GFLI database, shall omit the packaging phase of the additive. Information to calculate the impact of packaging will be considered in the future, in order to enable the user of the GFLI datasets to calculate the impact of the packaging when calculating the environmental footprint of its premix or compound feed.

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 for slaughterhouses are currently not available.

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## Annex 1 Current coverage of GFLI datasets

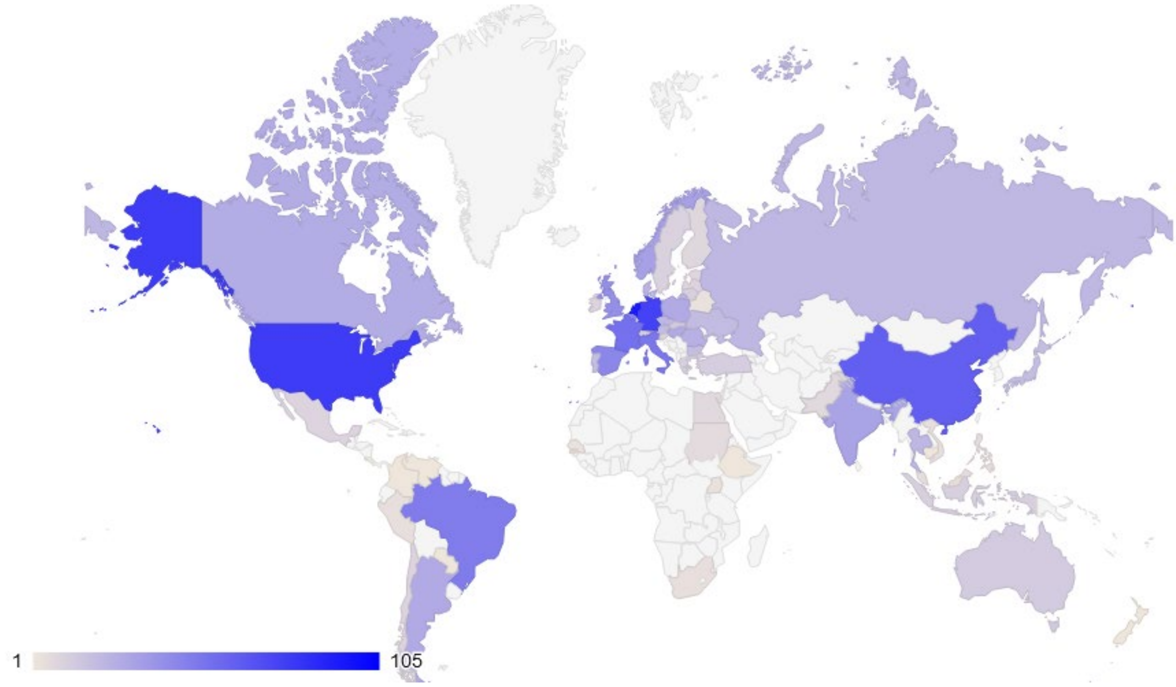


*Figure 3 Number of datasets per country in the GFLI database*

Figure 3 illustrates for which countries most feed ingredients exist within the GFLI database. These feed ingredients could be either cultivated or processed products. In addition to this, there are datasets on state/province level for Canada (32 cultivation datasets from GFLI Canada) and United States (105 cultivation datasets from USDA) that are not shown in Figure 3. Also, there are datasets that represent a region containing multiple or all countries, these are: GLO (Global averages, 72 datasets), RER (Region Europe, 105 datasets) and RNA (Region North-America, 6 datasets).

# Annex 2 DQR method

## Annex 2.1 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.

*Table 17 DQR criteria used in connection to activity data and background data for production and combustion/conversion*

| 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 |

The scoring of the DQR is determined based on a rating system derived from the DQR system applied in the PEF. Table 17 gives an overview of the criteria for the rating.

*Table 18 DQR criteria matrix*

| | 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 |

## Annex 2.2 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 4).

Figure 4 shows the list of activity (foreground and background) data to be evaluated.

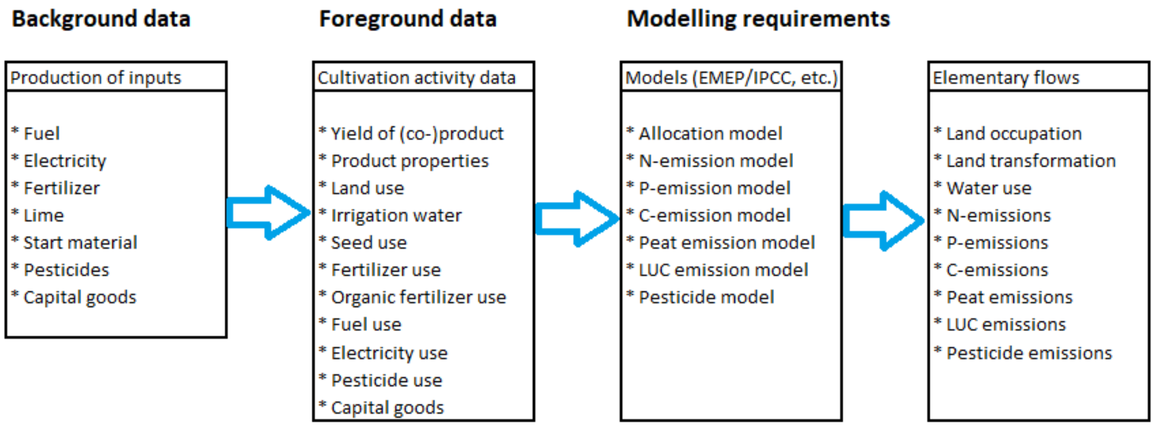


*Figure 4 Basic scheme to evaluate the DQR of agricultural processes*

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:

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

Table 19 gives an overview of activity data and how the DQR is calculated.

*Table 19 Activity data mentioned in the Formula and how they relate to environmental impact and DQR*

| 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 and Agribalyse datasets. | Mathematical average of:<br>1. Production (Ter, Tir)<br>2. Use quantity (Ter.Tir. Gr. P)<br>3. Combustion data (Ter. Tir) |
| **Eu** | Electricity use [kwh/ha] | Quantity times production data (country specific) | Mathematical average of:<br>1. Production (Ter, Tir)<br>2. Use quantity (Ter.Tir. Gr. P) |
| **F** | Fertilizer use [kg product/ha] | Quantity times production data (AFP data sets and Ecoinvent datasets) | Mathematical average of:<br>1. Production (Ter.Tir)<br>2. Use quantity (Ter.Tir. Gr. P) |

| | | | |
|---|---|---|---|
| **Fo** | Organic fertilizer use [kg product/ha] | Quantity times production data (AFP data set) | Mathematical average of:<br>1. Production (Ter.Tir)<br>2. Use quantity (Ter.Tir. Gr. P) |
| **L** | Lime use [kg $CaCO_3$/ha] | Quantity times production data (Ecoinvent data set) | Mathematical average of:<br>1. Production (Ter.Tir)<br>2. Use quantity (Ter, TiR, GR, P) |
| **Su** | Seed use | Quantity times production data (AFP) | Mathematical average of:<br>1. Production (Ter.Tir)<br>2. Use quantity (Ter.Tir. Gr. P) |
| **Pu** | Pesticides use | Quantity times production data (AFP) | Mathematical average of:<br>1. Production (Ter.Tir)<br>2. 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:<br>1. Production (Ter.Tir)<br>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 (see annex 4) | Quantity |

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 that we know 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%.

*Table 20 Contribution of environmental impacts related to activity data and connected production and combustion (derived from PEFCR Feed)*

| | Wheat UK | Soybean BR | Rapeseed DE | Maize FR | Average |
|---|---|---|---|---|---|
| **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 |

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 2.2 Data quality of processing agricultural products**

The environmental impact of processing 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.

*Table 21 Activity data of crop processing*

| 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 |

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 coproducts 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.

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 located quite nearby 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 and potatoes, while other crops such as seeds, beans and grains can be transported long distances for processing. The data on origin of crops are important due to the variability in the 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.

*Table 22 Average contribution of environmental impacts of processing activity data and connected production and combustion data*

| 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% | |

**Annex 2.2 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.

*Table 23 Activity data of animal processing*

| 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 |

# Annex 3 Default allocation factors

*Table 24 Default allocation factors (Blonk et al., 2022)*

| Process stage | Product | Input | Economic allocation fraction | Mass allocation fraction | Gross energy allocation fraction |
|---|---|---|---|---|---|
| Cultivation | Barley grain | harvested plant | 86.74% | 71.33% | 70.07% |
| Cultivation | Oat grain | harvested plant | 85.6% | 69.66% | 69.4% |
| Cultivation | Triticale grain | harvested plant | 85.99% | 69.66% | 69.30% |
| Cultivation | Wheat grain | harvested plant | 86.38% | 69.66% | 69.99% |
| Dry milling | Wheat germ | Wheat | 3.19% | 1.99% | 2.24% |
| Dry milling | Wheat middlings & feed | Wheat | 6.55% | 12.46% | 12.53% |
| Dry milling | Wheat bran | Wheat | 6.3% | 11.96% | 12.26% |
| Dry milling | Wheat flour | Wheat | 83.96% | 73.59% | 72.97% |
| Dry milling | Rice bran | Rice | 3.35% | 10.32% | 9..41% |
| Dry milling | Rice husk | Rice | 1.34% | 20.63% | 18.82% |
| Dry milling | White rice | Rice | 84.64% | 60.07% | 62.44% |
| Dry milling | Rice brokens | Rice | 10.67 | 8.98% | 9.33 |
| Wet milling | Wheat bran | Wheat | 8.22% | 18.0% | 16.93% |
| Wet milling | Wheat gluten feed | Wheat | 5.03% | 7.98% | 7.6% |
| Wet milling | Wheat gluten meal | Wheat | 29.02% | 10.04% | 12.1% |
| Wet milling | Wheat starch | Wheat | 54.36% | 53.98% | 58.47% |
| Wet milling | Wheat starch slurry | Wheat | 3.37% | 10.0% | 4.9% |
| Wet milling | Potato juice concentrated | Potato | 0.97% | 11.71% | 10.91% |
| Wet milling | Potato protein | Potato | 11.53% | 5.58% | 4.83% |
| Wet milling | Potato pulp pressed | Potato | 1.77% | 8.95% | 33.17% |
| Wet milling | Potato starch dried | Potato | 85.73% | 73.76% | 51.09% |
| Crushing (solvent) | Crude soy bean oil | Soy beans | 33.59% | 21.68% | 35.62% |
| Crushing (solvent) | Soy bean hulls | Soy beans | 2.11% | 7.43% | 5.66% |
| Crushing (solvent) | Soy bean meal (no added hulls) | Soy beans | 64.3% | 70.89% | 58.72% |
| Crushing (cold pressing) | Crude soybean oil | Soy beans | 24.67% | 16.08% | 25.69% |
| Crushing (cold pressing) | Soybean expeller | Soy beans | 75.33% | 83.92% | 74.31% |
| Crushing (solvent) | Rapeseed meal | Rape seed | 24.81% | 55.16% | 64.84% |
| Crushing (solvent) | Crude rapeseed oil | Rape seed | 75.19% | 44.84% | 35.16% |
| Crushing (cold pressing) | Rapeseed expeller | Rape seed | 40.17% | 66.23% | 49.2% |
| Crushing (cold pressing) | Crude rapeseed oil | Rape seed | 59.83% | 33.77% | 50.8% |
| Crushing (cold pressing) | Palm kernels | Palm Fruit Bunches | 10.75% | 20.51% | 15.98% |
| Crushing (cold pressing) | Crude palm oil | Palm Fruit Bunches | 89.25% | 79.49% | 84.02% |
| Crushing (cold pressing) | Crude palm kern oil | Palm kernels | 89.25% | 50.19% | 66.05% |
| Crushing (cold pressing) | Palm kernel expeller | Palm kernels | 10.75% | 49.81% | 33.95% |
| Rendering | Food grade fat | Food grade animal material | 72.99% | 40.46% | 51.38% |

| | | | | | |
|---|---|---|---|---|---|
| Rendering | Greaves meal | Food grade animal material | 27.01% | 59.54% | 48.62% |
| Rendering | Fish meal | Landed industry fish | 87.49% | 81.5% | 66.58% |
| Rendering | Fish oil | Landed industry fish | 12.51% | 18.5% | 33.42% |

# Annex 4 Default modelling of agriculture

### Annex 4.1 'Cradle' start material

Start material is the starting input, such as seeds. In case the amount of 'cradle' material is not reported, crop specific defaults will be used to include the amount of start material and its impact. The amount of this 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 25 below.

*Table 25 Global average seed input for common feed crops*

| 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 |

### Annex 4.2 Pesticides

Pesticide emissions shall be modelled as specific active ingredients. The USEtox life cycle impact assessment method has a built-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 a 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 4.3 Default emission modelling for GFLI

Table 26 gives an overview of what emissions are considered and which methods are used to quantify the emission flow. Besides this, not all emissions are considered for the most important aspects. For instance, laughing gas emissions are quantified for fertilizer inputs, manure inputs and crop residues, but is "not applicable" for lime inputs. Please note that ammonia emissions from manure is based on the tier 1 IPCC methods, whereas for fertilizer use ammonia emissions are based on the more detailed method described in EMEP/EEA.

*Table 16 Overview of modelled emissions, literature source and which aspects are included for the calculations*

| Emission | Level | Method | Fertilizer | Manure | Crop residues | Lime |
|---|---|---|---|---|---|---|
| (In)direct laughing gas emissions | Tier 1 | IPCC (IPCC | Yes | Yes | Yes | - |
| Ammonia emissions | Tier 1 | 2019b) | No | Yes | No | - |
| Nitrate emissions | Tier 1 | | Yes | Yes | Yes | - |
| Carbon dioxide emissions | Tier 1 | | Yes | - | - | Yes |
| Nitrogen monoxide emissions | Tier 1 | EMEP/EEA | Yes | Yes | No | - |
| Ammonia emissions | Tier 2 | (European | Yes | No | No | - |

| | | | | | |
|---|---|---|---|---|---|
| | Environment Agency 2016) | | | | |
| Phosphorus emissions | ReCiPe (Huijbregts et al. 2016b) | Yes | Yes | No | - |
| Heavy metal emissions | Nemecek & Schnetzer (Nemecek and Schnetzer 2011) | Yes | Yes | Yes | Yes |

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

- Methane emissions for rice cultivation

## Nitrous oxide ($N_2O$) emissions

There are a number of pathways that result in nitrous oxide emissions, which can be divided into direct emissions (release of $N_2O$ directly from N inputs) and indirect emissions ($N_2O$ emissions through a more intricate mechanism). In addition to nitrous emissions due to N additions, there are other activities that can result in direct nitrous oxide emissions, such as the drainage of organic soils, changes in mineral soil management, and emissions from urine and dung inputs to grazed soils. These latter two categories are not taken into account in the crop cultivation models, as it is assumed that crops are cultivated on cropland and the organic matter contents of the soils does not substantially change, and that cropland is not grazed. The emissions from grazing of pastureland are however included in the animal system models. The following equations and definitions are derived from IPCC methodologies on $N_2O$ emissions from managed soils;

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

EQUATION 1 (IPCC, 2019B)

Where,

*$N_2O - N_{Direct}$ = annual direct $N_2O$–N emissions produced from managed soils, [kg $N_2O$–N]*
*$N_2O - N_{N\ inputs}$ = annual direct $N_2O$–N emissions from N inputs to managed soils, [kg $N_2O$–N]*
*$N_2O - N_{OS}$ = annual direct $N_2O$–N emissions from managed organic soils, [kg $N_2O$–N]*
*$N_2O - N_{PRP}$ = annual direct $N_2O$–N emissions from urine and dung inputs to grazed soils, [kg $N_2O$–N]*

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

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

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

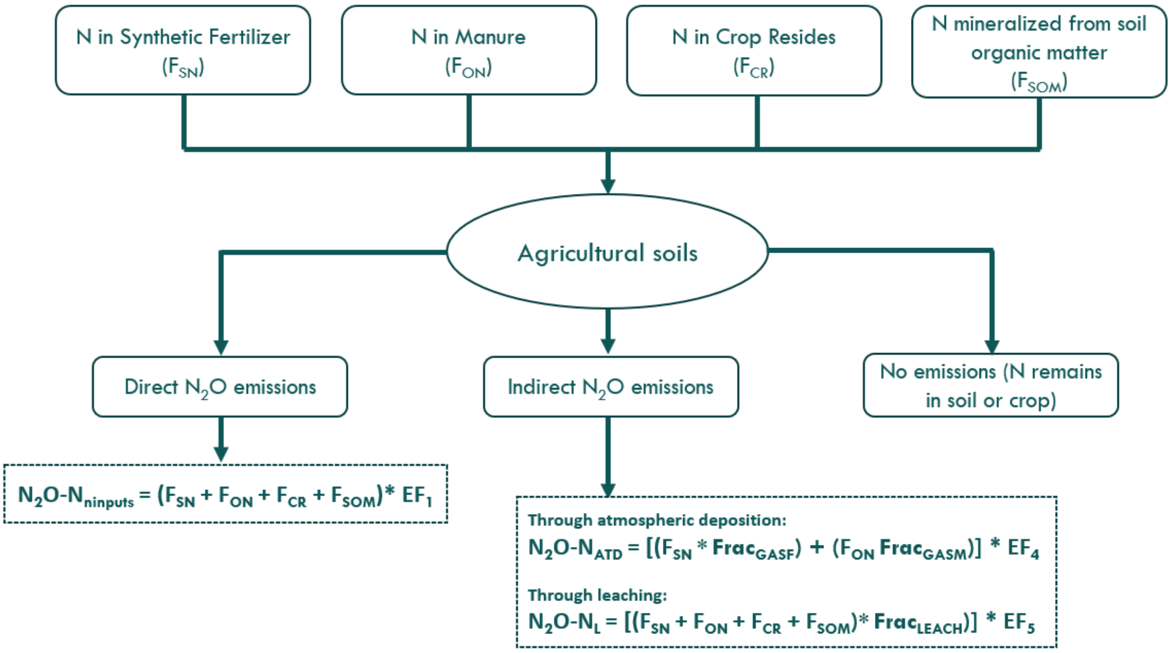


*Figure 5 Nitrous oxide emission (direct and indirect) due to different N inputs (IPCC 2019b).*

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

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

EQUATION 1 (IPCC, 2019B)

Where,
*$F_{SN}$ = the amount of synthetic fertilizer N applied to soils, [kg N]*
*$F_{ON}$ = the amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, [kg N]*
*$F_{CR}$ = the amount of N in crop residues (above-ground and below-ground), including N-fixing crops (leguminous), and from forage/pasture renewal, returned to soils, [kg N]*
*$F_{SOM}$ = the amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management, [kg N]*
*$EF_1$ = emission factor for $N_2O$ emissions from N inputs, $[\frac{kg\ N_2O-N}{kg\ N\ input}]$*

As mentioned before, the contribution of $F_{SOM}$ is incorporated in the emissions from land use change. $F_{CR}$ is dependent on the type of crop and yield and is determined separately. The IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019b) provides guidance on how to do this using an empirical formula and data for a limited number of crops and crop types. The emission factor $EF_1$ in Equation 2 has a default value of 0.01 (i.e. 1% of mass of N from fertilizer and crop residue will be converted to $N_2O$).

In GFLI the direct $N_2O$ emissions are modelled according to the IPCC Tier 1 approach. The uncertainty range of the $EF_1$ emission factor is very high (0.003 – 0.03) because climatic conditions, soil conditions and agricultural soil management activities (e.g. irrigation, drainage, tillage practices) affect direct emissions.

$F_{SN}$ has been determined using mainly data from Pallière (2011). The contribution of $F_{ON}$ has been determined on a country basis, as described in the methodology report of the Feedprint study (Vellinga et al., 2013a), which formed the basis of the crop cultivation models in this study.
There are two other, indirect, mechanisms that also contribute to the total $N_2O$ emissions:

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

EQUATION 3 (IPCC, 2019B)

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

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

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

EQUATION 2 (IPCC, 2019B)

Where,
*$F_{SN}$ = annual amount of synthetic fertilizer N applied to soils, [kg N]*
*$F_{ON}$ = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, [kg N]*
*$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as $NH_3$ and $NO_x$,* $\left[\frac{kg\ N\ volatilized}{kg\ N\ applied}\right]$
*$Frac_{GASM}$ = fraction of applied organic N fertilizer materials ($F_{ON}$) and of urine and dung N deposited by grazing animals ($F_{PRP}$) that volatilizes as $NH_3$ and $NO_x$,* $\left[\frac{kg\ N\ volatilized}{kg\ N\ applied\ or\ deposited}\right]$
*$EF_4$ = emission factor for $N_2O$ emissions from atmospheric deposition of N on soils and water surfaces,* $\left[\frac{kg\ N_2O\text{–}N}{kg\ NH_3\text{–}N + NO_x\text{–}N\ volatilized}\right]$
*$F_{PRP}$ = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, [kg N]*

No mixed enterprise farming systems are considered. Therefore, in the crop cultivation models, $F_{PRP}$ was set to 0 (no urine and dung from grazing animals). However, emissions from grazing were taken into account in the animal systems, where appropriate. The default emission factor $EF_4$ and the default fractions are listed in Table 28. Equation 5 shows the calculation procedure for determining $N_2O$ emission from leaching of applied N from fertilizer (SN and ON), crop residue (CR), grazing animals (PRP) and soil organic matter (SOM).

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

EQUATION 3 (IPCC, 2019B)

*$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff,* $\left[\frac{kg\ N}{kg\ of\ N\ additions}\right]$
$EF_5$= emission factor for $N_2O$ emissions from N leaching and runoff, $\left[\frac{kg\ N_2O\text{–}N}{kg\ N\ leached\ and\ runoff}\right]$

## Ammonia ($NH_3$) and nitrate ($NO_3$-) emissions – tier 1

Again, the IPCC calculation rules (IPCC, 2019b) were applied to determine the ammonia and nitrate emissions. This approach of modelling ammonia volatilization was used only for emissions from manure; the ammonia volatilization from inorganic fertilizer was indeed modelled following EMEP/EEA guidelines. It was assumed that all nitrogen that volatizes converts to ammonia, and that all nitrogen that leaches is emitted as nitrate. In essence, Equation 6 & Equation 7 are the same as the aforementioned equations for nitrous emissions from atmospheric deposition and leaching (Equation 4 & Equation 5) but without the secondary conversion to nitrous oxide.
Ammonia ($NH_3$) emissions:

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

EQUATION 4 (IPCC, 2019B)

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

Nitrate ($NO_3^-$) emissions to water:

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

EQUATION 5 (IPCC, 2019B)

Where,
*$NO_3^-$-N = nitrate produced from leaching of N from managed soils, [kg $NO_3^-$-N]*
*The IPCC includes a note "that in the Tier 1 method, for wet climates or dry climate regions where irrigation (other than drip irrigation) is used, the default $Frac_{leach}$ is 0.24. For dry climates, the default $Frac_{leach}$ is zero." Now including a $Frac_{wet}$ to better quantify the nitrate emissions that are taken place in agricultural systems. The $Frac_{wet}$ represents the share of wet climate within a country, data is taken from the land use change tool (Blonk Consultants, 2021).*

## Carbon dioxide ($CO_2$) emissions

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

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

EQUATION 6 (IPCC, 2019B)

Where,
*$CO_2$–$C_{em}$ = C emissions from lime, dolomite and urea application, [kg C]*
*$M_{limestone}$, $M_{dolomite}$, $M_{urea}$ = amount of calcic limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) or urea respectively, in [kg]*
*$EF_{limestone}$, $EF_{dolomite}$, $EF_{urea}$ = emission factor, $\left[\frac{kg\ C}{kg\ of\ limestone, dolomite\ or\ urea}\right]$*

Default emission factors are reported in Table 27.

## IPCC tier 1 emissions factors and constants

*Table 27 IPCC Tier 1 emission factors and constants.*

| IPCC Tier 1 Emission factors and constants [and units] | Value [IPCC 2006] | Value [IPCC 2019] |
|---|---|---|
| $EF_1 \left[\frac{kg\ N_2O - N}{kg\ N_{applied}}\right]$ | *0.01* | *0.01* |
| $EF_4 \left[\frac{kg\ N_2O - N}{kg\ N_{volatized}}\right]$ | *0.01* | *0.01* |
| $EF_5 \left[\frac{kg\ N_2O - N}{kg\ N_{leached}}\right]$ | *0.0075* | *0.011* |
| $EF_{Dolomite} \left[\frac{kg\ CO_2 - C}{kg\ Dolomite}\right]$ | *0.13* | *0.13* |
| $EF_{Lime} \left[\frac{kg\ CO_2 - C}{kg\ lime}\right]$ | *0.12* | *0.12* |
| $EF_{Urea} \left[\frac{kg\ CO_2 - C}{kg\ Urea}\right]$ | *0.2* | *0.2* |
| $Frac_{GASM} \left[\frac{kg\ NH_3 - N}{kg\ N_{in\ manure\ applied}}\right]$ | *0.2* | *0.21* |
| $Frac_{GASF} \left[\frac{kg\ NH_3 - N}{kg\ N_{in\ fertilizer\ applied}}\right]$ | *0.1* | *0.11* |
| $Frac_{LEACH} \left[\frac{kg\ NO_3^- - N}{kg\ N_{applied}}\right]$ | *0.3* | *0.24* |
| *Conversion from kg CO2-C to kg CO2* | $\left(\frac{44}{12}\right)$ | $\left(\frac{44}{12}\right)$ |
| *Conversion from kg N2O-N to kg N2O* | $\left(\frac{44}{28}\right)$ | $\left(\frac{44}{28}\right)$ |
| *Conversion from kg NH3-N to kg NH3* | $\left(\frac{17}{14}\right)$ | $\left(\frac{17}{14}\right)$ |
| *Conversion from kg NO3--N to kg NO3-* | $\left(\frac{62}{14}\right)$ | $\left(\frac{62}{14}\right)$ |

## Nitric Oxide (NO) emissions

In GFLI, nitric oxide emissions from fertilizer use are considered. Although nitric oxide is produced as an intermediate product of the nitrification and denitrification processes, no methodology has been developed in the IPCC guidelines of 2006 to quantify its emission. A default value of 0.04 kg $NO_2$ per kg of N fertilizer and kg N from manure applied is used for GFLI (European Environment Agency 2016).

## Ammonia ($NH_3$) emissions – tier 2

For ammonia emissions from inorganic fertilizers a more detailed tier 2 approach is used based on emission factors for specific type of fertilizers described by EMEP/EEA (European Environment Agency, 2016). All inventoried nitrogen-containing fertilizers have their own specific emission factor described in table 28.

*Table 28 Emission factors for ammonia emissions from fertilizers (g $NH_3$/kg N applied) (European Environment Agency, 2016)*

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

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

Due to the lack of data on the pH of soils, it is assumed that all soils around the world are "normal". Using the climate zone criteria described in the reference and average temperatures of countries around the world, each country is classified as "cool", "temperate" or "warm".

## Phosphorus emissions

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

## Heavy metal emissions

The emissions of heavy metals was based on a methodology described in Nemecek & Schnetzer (2012). The emissions are the result of inputs of heavy metals to the soil due to the application of fertilizers and manure, and deposition and outputs of heavy metals due to leaching and removal of biomass. The heavy metal content of fertilizers and manure was based on literature as stated in Table 29 and Table 30, respectively. The deposition of heavy metals is stated in Table 31.

*Table 29 Heavy metal content of fertilizers*

| Mineral fertilizers | Unit | Cd | Cr | Cu | Hg | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| Urea | mg/kg | 2.796 | 36.301 | 12.116 | 0.047 | 9.739 | 25.583 | 94.598 |
| Nitrogen solutions | mg/kg | 1.800 | 23.370 | 7.800 | 0.030 | 6.270 | 16.470 | 60.900 |
| NPK compound | mg/kg | 6.840 | 94.005 | 18.195 | 0.060 | 16.755 | 18.405 | 157.230 |
| Anhydrous ammonia | mg/kg | 4.920 | 63.878 | 21.320 | 0.082 | 17.138 | 45.018 | 166.460 |
| Ammonium nitrate | mg/kg | 2.100 | 27.265 | 9.100 | 0.035 | 7.315 | 19.215 | 71.050 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Calcium ammonium nitrate | mg/kg | 1.658 | 22.656 | 8.883 | 0.036 | 6.975 | 15.877 | 62.940 |
| Ammonium phosphate | mg/kg | 23.835 | 326.648 | 57.305 | 0.193 | 54.929 | 50.268 | 522.890 |
| Ammonium sulfate | mg/kg | 1.260 | 16.359 | 5.460 | 0.021 | 4.389 | 11.529 | 42.630 |
| Triple superphosphate | mg/kg | 18.960 | 260.640 | 43.440 | 0.144 | 42.384 | 32.160 | 402.720 |
| Single superphosphate | mg/kg | 8.295 | 114.030 | 19.005 | 0.063 | 18.543 | 14.070 | 176.190 |
| PK compound | mg/kg | 8.712 | 120.736 | 20.966 | 0.066 | 19.976 | 14.916 | 185.944 |
| Ground rock | mg/kg | 12.640 | 173.760 | 28.960 | 0.096 | 28.256 | 21.440 | 268.480 |
| Potassium chloride | mg/kg | 0.060 | 3.480 | 2.880 | 0.000 | 1.500 | 0.480 | 3.720 |
| Potassium sulphate | mg/kg | 0.050 | 2.900 | 2.400 | 0.000 | 1.250 | 0.400 | 3.100 |
| Lime | mg/kg | 0.280 | 8.249 | 8.169 | 0.040 | 5.886 | 5.446 | 37.481 |

*Table 30 Heavy metal content of manure*

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

The above European values are also used for other continents because data is not available, incomplete or it is not stated if the values are 'per kg dry matter' or 'per kg manure as is'. Please note that ranges in heavy metal contents of animal manure are large as shown in Table 30. Please note that the amount of copper (Cu) and zinc (Zn) in pig slurry and manure is high because additional copper and zinc is added to the feed by pig farmers for animal health reasons. It is assumed that only pig and poultry manure is applied in cultivation of arable crops[1] because cattle systems are often closed-loop systems. The ratio pig / poultry manure is based on FAO data on the amount of available nitrogen per type of animal manure.

*Table 31 Deposition of heavy metals (Nemecek and Schnetzer 2012)*

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

Heavy metals are removed from the soil via removal of biomass and via leaching. The heavy metal content of biomass of crops is shown in Table 31. Leaching of heavy metals to ground water is mentioned in Table 32.

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

*Table 31 Heavy metals in biomass (Delahaye et al. 2003)*

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

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

*Table 32 Heavy metal leaching to groundwater (Nemecek and Schnetzer 2012)*

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

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

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

EQUATION 7

$A_i$ = *allocation factor for the share of agricultural inputs in the total inputs for heavy metal i*
$M_{agro\ i}$ = *input due to agricultural activities (fertilizer and manure application) for heavy metal i*
$M_{deposition\ i}$ = *input due to deposition for heavy metal i*

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

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

EQUATION 8

Where,

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

$\boldsymbol{m_{leach\ i}}$ = average amount of heavy metal emission

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

Heavy metals emissions to the soil are calculated as follows:

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

EQUATION 9

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

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

EQUATION 10

Where,
$\boldsymbol{A}$ = *fertilizer application (kg/ha/yr)*
$\boldsymbol{A_{content\ i}}$ = *heavy metal content i for fertilizer applied*
$\boldsymbol{B}$ = *manure application (kg DM/ha/yr)*
$\boldsymbol{B_{content\ i}}$ = *heavy metal content i for manure applied*
$\boldsymbol{C}$ = *deposition*

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

EQUATION 11

Where,
$\boldsymbol{D}$ = *yield (kg DM/ha/yr)*
$\boldsymbol{D_{content\ i}}$ = *heavy metal content i for crop*

*When more heavy metals are removed from the soil via leaching and biomass than is added to the soil via fertilizers, manure and deposition, the balance can result in a negative emission.*

## Emissions from drained peat soils

In previous versions of GFLI, peat emissions from drained soils were only considered for a limited number of crops. Now this is included for all crops. For all GHG emissions estimations of drained peat soils, the calculation is based on the factor $A_{crop,\ country}$, which for each crop-country combination is defined by

$$A_{crop,\ country} = \frac{harvested\ area\ of\ crop\ in\ country\ on\ drained\ peat\ soils}{total\ harvested\ area\ of\ crop\ in\ country}$$

Once $A_{crop,\ country}$ is determined, $CO_2$ emission factors are extrapolated from the specific country National Inventory Report (NIR) 2019 submission (average of 2012-2017 data). In case the country does not submit a NIR, and for N2O emissions factors, IPCC (2013) supplement is used (IPCC Guidelines on Wetlands, 2006[2]). To calculate the GHG emissions from peat oxidation per ha crop in each country, the emission factors are multiplied by the $A_{crop,\ country}$. $CO_2$ emissions from the extraction of peat and peat burning due to fires are not considered, and only the on-site peat emissions from drained organic soil are considered. The emission factors are dependent on type of land occupation (orchard, palm, cropland, paddy rice and grassland) and climate (tropical, temperate and boreal). We assumed that each country has one dominant climate.

$A_{crop,\ country}$ is determined in two steps

1. **Calculation of country-level average values:** Estimation of a country-specific value $A_{country}$, i.e. not on a crop-specific level. Data on the parameter $A_{country}$ was collected from National

[2] https://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html

Inventory Reports (2012-2017 average)[3]. When not available, $A_{country}$ is extrapolated with data from FAOSTAT.

2. **Correction of A to crop-specific data:** To obtain a crop-country specific value for A, we used geospatial data for cultivated peat soils[4] and crop cultivation[5], the latter representing yields in the year 2000. For each crop-country combination, we calculated the value for $A_{crop,\ country}$ based on these geospatial datasets, which we call $A^{geo}_{crop,\ country}$ to obtain a more crop-specific model of peat-related GHG emissions. As the data is relatively old and also has data gaps, we used $A^{geo}_{crop,\ country}$ only to correct the country-level averages $A_{country}$ calculated in step 1. If $A^{geo}_{country}$ is the country-level weighted (by harvested area) average of the $A^{geo}_{crop,\ country}$, we therefore set

$$A_{crop,\ country} = A_{country} \cdot \frac{A^{geo}_{crop,\ country}}{A^{geo}_{country}}.$$

In this way, we take into account crop-specific variations of drained organic peat soils. Although some crops, in particular tubers, seem to be cultivated more frequently on peat-rich soils, it should be noted that the variability of $A^{geo}_{crop,\ country}$ is typically less than 20%, i.e. the crop type has a much smaller influence on the GHG emissions from peat oxidation than the country.

For Indonesia and Malaysia, the area of drained organic soil cultivated with palm oil is well documented in literature (Schrier-Uijl et al. 2013). Therefore, specific values of A for palm are used, and the country average is adjusted based on the crop specific harvested areas derived from FAOSTAT.

It should be noted that our approach to model greenhouse gas emissions from peat soils is a rough approach and should be considered a first order approximation. The real situation for a specific field of a certain crop in a country can of course deviate substantially.

Since the impact of drained peat oxidation can be large on climate change, and given its intrinsic uncertainty, it was decided to give the possibility to show the impact of peat separately (similar as LUC). For this, one existing and two additional substances are used:

- Carbon dioxide, peat oxidation
- Methane, peat oxidation
- Dinitrogen monoxide, peat oxidation

For LCA software users, please check if these substances are included in carbon footprint related impact categories. Otherwise, the user needs to adapt the method to include peat emissions in their carbon footprint numbers. It is advised to show peat emission impacts separately, similar as greenhouse gas emissions related to land use change.

## Regionalized emissions and resources

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

*Table 33 Update and regionalized substances in GFLI, with Netherlands as an example*

| Substance name GFLI v1 | Substance name GFLI v2 |
|---|---|
| Occupation, annual crop | Occupation, annual crop, NL |
| Occupation, permanent crop | Occupation, permanent crop, NL |

[3] https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2019
[4] http://www.fao.org/geonetwork/srv/en/metadata.show?id=56901&currTab=distribution
[5] http://www.earthstat.org/harvested-area-yield-175-crops/

| | |
|---|---|
| Occupation, grassland/pasture/meadow | Occupation, grassland/pasture/meadow, NL |
| Transformation, from annual crop | Transformation, from annual crop, NL |
| Transformation, from forest, unspecified | Transformation, from forest, extensive, NL |
| Transformation, from grassland | Transformation, from grassland/pasture/meadow, NL |
| Transformation, from permanent crop | Transformation, from permanent crop, NL |
| Transformation, to annual crop | Transformation, to annual crop, NL |
| Transformation, to grassland | Transformation, to grassland/pasture/meadow, NL |
| Transformation, to permanent crop | Transformation, to permanent crop, NL |
| Ammonia | Ammonia, NL |
| Nitrogen monoxide | Nitrogen monoxide, NL |
| Nitrate | Nitrate, NL |
| Phosphorus | Phosphorus, NL |
| Water, unspecified natural origin, NL | Water, unspecified natural origin, NL |

Whether regionalized flows lead to different environmental impacts due to (potentially) different emissions factors depends on the method that has been used.

## Specific Emissions

### Methane emissions in rice cultivations

Methane emissions that are a result of rice cultivation have been inventoried for rice cultivations in GFLI. In this GFLI database the emission factors for rice cultivation are based on information from a single public source. FAOstat reports on the "implied emissions factor for $CH_4$" for rice cultivation for 120+ countries (FAOSTAT, 2019). This factor is converted from gram methane/harvested square meter to kg biogenic methane per harvested hectare in the LCIs for rice cultivation.

### Annex 4.4 Default energy use for activities

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

*Table 34*

| 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 | |

| | | | |
|---|---|---|---|
| | Manure injector, vacuum tank 20 $m^3$ | 43.27 | Specify type of equipment used for manure spreading. By default, injectors are used for pig manure and much spreader for poultry manure. |
| | 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). |

# Annex 5 Default background data

*Table 35 Default background data*

| Source | Background datasets |
|---|---|
| **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 |
| **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 |

| Source | Background datasets |
|---|---|
| **Energy** | Energy, from diesel burned in machinery/RER Economic |
| **Capital goods** | Basic infrastructure, at farm/GLO Economic |
| **Capital goods** | Silo, for grain storage, at farm/GLO Economic |
| **Capital goods** | Tractor, 4-wheel, agricultural {GLO}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/RER Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Ammonia, as 100% NH3 (NPK 82-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/RER Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Ammonium nitrate, as 100% (NH4)(NO3) (NPK 35-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/RER Economic |

| | |
|---|---|
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/RER Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/RER Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/RER Economic |

| | |
|---|---|
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Liquid urea-ammonium nitrate solution (NPK 30-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/RER Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Nitric acid, in water (60% HNO3) (NPK 13.2-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/RER Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/RME Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | NPK compound (NPK 15-15-15), market mix, at regional storage/UN-EASIA Economic |
| **Fertilizer production** | Phosphate rock (32% P2O5, 50% CaO) (NPK 0-32-0), at mine/RER Economic |
| **Fertilizer production** | Phosphoric acid, merchant grade (75% H3PO4) (NPK 0-54-0), at plant/RER Economic |
| **Fertilizer production** | PK compound (NPK 0-22-22), at plant/RER Economic |
| **Fertilizer production** | Potassium chloride (NPK 0-0-60), at plant/RER Economic |

| | |
|---|---|
| **Fertilizer production** | Potassium sulfate (NPK 0-0-50) (Mannheim), at plant/RER Economic |
| **Fertilizer production** | Single superphosphate, as 35% Ca(H2PO4)2 (NPK 0-21-0), at plant/RER Economic |
| **Fertilizer production** | Triple superphosphate, as 80% Ca(H2PO4)2 (NPK 0-48-0), at plant/RER Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/FSU Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/OCE Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/RAF Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/RER Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/RLA Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/RME Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/RNA Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/SAS Economic |
| **Fertilizer production** | Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), market mix, at regional storage/UN-EASIA Economic |
| **Electricity production** | Electricity, low voltage {AR}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {AT}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {AU}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {BE}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {BG}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {BR}\| market group for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {BY}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CA}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CH}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CL}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CN}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CO}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CR}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CY}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {CZ}\| market for \| Cut-off, S - Copied from ecoinvent |

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|---|---|
| **Electricity production** | Electricity, low voltage {DE}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {DK}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {EE}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {EG}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {ES}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {ET}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {FI}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {FR}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {GB}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {GR}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {HU}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {ID}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {IE}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {IN}\| market group for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {IT}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {JP}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {KH}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {LT}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {LV}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {MX}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {MY}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {NL}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {NO}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {NZ}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {PE}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {PH}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {PK}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |

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| **Electricity production** | Electricity, low voltage {PL}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {PT}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {PY}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RAF}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RAS}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RER}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RLA}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RME}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RNA}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RO}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {RU}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {SD}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {SE}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {SI}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {SK}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {SN}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {TH}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {TR}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {UA}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {US}\| market group for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {UY}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {VE}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {VN}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {ZA}\| market for \| Cut-off, S - Copied from ecoinvent |
| **Electricity production** | Electricity, low voltage {AR}\| market for electricity, low voltage \| Cut-off, S - Copied from ecoinvent |
| **Heat production** | Heat, district or industrial, natural gas {Europe without Switzerland}\| heat production, natural gas, at industrial furnace >100kW \| Cut-off, S - Copied from ecoinvent |
| **Heat production** | Heat, district or industrial, natural gas {RoW}\| heat production, natural gas, at industrial furnace >100kW \| Cut-off, S - Copied from ecoinvent |

| | |
|---|---|
| **Heat production** | Heat, district or industrial, other than natural gas {RoW}\| heat production, heavy fuel oil, at industrial furnace 1MW \| Cut-off, S - Copied from ecoinvent |
| **Heat production** | Heat, district or industrial, other than natural gas {RoW}\| heat production, light fuel oil, at industrial furnace 1MW \| Cut-off, S - Copied from ecoinvent |
| **Pesticide production** | Fungicide, at plant/RER Economic |
| **Pesticide production** | Herbicide, at plant/RER Economic |
| **Pesticide production** | Insecticide, at plant/RER Economic |

## Annex 6 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. The seaship distance is according to default transport of the PEFCR Feed version 4.2 annex 6 (PEFCR Feed, 2020), unless further specified.

*Table 36 Transport distances (in km) and transport mode split for crops and processed crop products*

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| BE | NL | Oat | Process_to_Mix | 128 | 42 | 123 | 0 |
| **Country A** | **Country B** | **Base Product** | **Transport Moment** | **Lorry dist** | **Train dist** | **InlandShip dist** | **SeaShip dist** |
| 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 |
| 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 |
| **Country A** | **Country B** | **Base Product** | **Transport Moment** | **Lorry dist** | **Train dist** | **InlandShip dist** | **SeaShip dist** |
| 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 |
| 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 |
| **Country A** | **Country B** | **Base Product** | **Transport Moment** | **Lorry dist** | **Train dist** | **InlandShip dist** | **SeaShip dist** |
| 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 |
| 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 |
| **Country A** | **Country B** | **Base Product** | **Transport Moment** | **Lorry dist** | **Train dist** | **InlandShip dist** | **SeaShip dist** |
| 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 |
| | | | | | | | |
| 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 |
| **Country A** | **Country B** | **Base Product** | **Transport Moment** | **Lorry dist** | **Train dist** | **InlandShip dist** | **SeaShip dist** |
| 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 |
| 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 |

gfli

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