Sphera's Agricultural LCA Model

Part 2

Dataset Generation & Data Sources

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Abbreviations

The following overview of abbreviations is applicable to both documentations (Part 1 and Part 2).

General abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AWARE	Available Water Remaining
BNF	Biological Nitrogen Fixation
CCC	Crop Country Combinations
GIS	Geographical Information System
ILCD	International Reference Life Cycle Data System
KUE	Potassium Use Efficiency
LCA	Life Cycle Assessment
LCA FE	Life Cycle Assessment for Experts (formerly known as 'GaBi ts') Software
LCI	Life Cycle Inventory
LANCA®	Land Use Indicator Value Calculation in Life Cycle Assessment
LUC	Land Use Change
LULUC	Land Use and Land Use Change
MLC	Managed LCA Content, by Sphera (formerly known as 'GaBi ts databases')
NUE	Nitrogen Use Efficiency
PAS	Publicly Available Specifications
PEF	Product Environmental Footprint
PUE	Phosphorous Use Efficiency
SALCA	Swiss Agricultural Life Cycle Assessment

Organizational Units

AquaStat	FAO global information system on water resources and agricultural water management
ECN	European Competition Network of the European Commission
ESDAC	European Soil Data Centre
FAO	Food and Agriculture Organization of the United Nations
FAOStat	FAO global information system on food and agricultural data
IFA	International Fertilizer Association
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Centre of the European Commission
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
NRCS	National Resources Conservation Service of the USDA
OECD	Organization for Economic Cooperation and Development
USDA	United States Department of Agriculture
WULCA	Working group on the assessment of Use and depletion of water within LCA

Emissions

EF	Emission Factor
GHG	Greenhouse Gas
CH_4	Methane
CO_2	Carbon Dioxide
N_2O	Nitrous Oxide
NH_3	Ammonia
NO_2	Nitrogen Dioxide
NO_x	Nitric Oxides
SO_2	Sulphur Dioxide

Fertilizers

AN	Ammonium Nitrate
$CaCO_3$	Calcium Carbonate
CaO	Quicklime
DAP	Diammonium Phosphate
H_3PO_4	Phosphoric Acid
KCl	Potassium Chloride
MAP	Monoammonium Phosphate
NH_3	Ammonia
NPK	Nitrogen Phosphate Potassium
RP	Rock Phosphate
TSP	Triple Superphosphate
UAN	Urea Ammonium Nitrate

Elements

As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
Hg	Mercury
K	Potassium
K_2O	Potassium Oxide (typically listed as K in fertilizers)
N	Nitrogen
Ni	Nickel
P	Phosphorous
Pb	Lead
P_2O_5	Phosphate
Tl	Thallium
U	Uranium
Zn	Zinc

1. Introduction

Sphera's Agricultural LCA Model has been developed to assess the environmental impacts of crop cultivation from cradle to field gate using the most recent LCA-centred methodology for representing agricultural production systems. It is a robust and tested model, based on agreed standards for agricultural modelling in LCA that has been further developed from the first comprehensive and industry-leading model of 2003. The two current, main guiding standards for Agricultural modelling are:

- 2019 Refinement of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019)
- Product Environmental Footprint method (European Commission, 2021)

Another relevant guideline in this context is the GHG Protocol Land Sector and Removals Guidance Draft (GHG Protocol, 2022). The model was examined in relation to this guideline and no deviations were identified. The GHG Protocol Guidance mainly references the IPCC as well. The finalized version of the guidance remains to be published (expected in 2024).

Sphera's Agricultural LCA Model is a generic model that can be used by generally experienced LCA practitioners with and without in-depth agricultural expertise (e.g. for screening studies or scope 3 emission modelling). The model is intended to work with data that is readily available (i.e. data that can be retrieved from secondary sources or collected with reasonable effort as primary data) to conduct agricultural LCI and LCA studies. It is created with the LCA FE (LCA for Experts, formerly known as "GaBi ts") software system for life cycle engineering. It represents the basis for Sphera's own agricultural datasets, providing high quality LCI data following a consistent and scientific approach, included in the Sphera MLC background database.

The goal of the document is provide the relevant background information on the methodology and data applied to create these datasets. The model itself is described in the first part of the documentation (Part 1: Model and Methods). The present document organization is summarized below:

- Chapter 1: Introduction
- Chapter 2: Data Collection Goals & Principles
- Chapter 3: Methodological specifications
- Chapter 4: Limitations and Use Advice

2. Data Collection Goals & Principles

The goal and scope of developing agricultural LCI datasets according to the method described within this report can be summarized as follows:

- Create generic country specific crop cultivation datasets that can be used as background data in LCA studies or as starting point for scope 3 emission reporting
- The compilation of data should follow a consistent and scientific approach and should be comprehensible, easily reproducible and transparently documented
- The procedure should allow regular updates of the datasets
- The proposed approaches can also be used to generate proxy data to fill data gaps in more specific assessments (e.g. supply chain specific assessments).

In order to guarantee a comprehensible and reproducible approach, the following data source hierarchy has been applied to all generated datasets and is recommended to be used:

1) Recognized databases that contain consistent data for several crops, such as FAOStat, IFA, or USDA
2) Data from scientific meta-studies (e.g. GIS data files)
3) Values from single studies (peer reviewed) for missing values

This hierarchy can still lead to data gaps for several parameters and some crops and countries, hence, additional calculations were conducted to retrieve final values. Chapter 3 describes these approaches in depth.

Detailed information about system boundaries, functional units and other relevant information can be found in Part 1: Model & Methods.

Capital goods, animal draught, human labor as well as changes in soil organic carbon stocks are excluded (estimations on SOC changes for the dominant land use are provided with the LANCA® impact assessment; these values are not included in the impact assessment on climate change and potential C stock changes have not been part of the inventory compilation).

3. Methodological specifications

The following chapter describes the specific approaches as well as data sources and default values defined for each of the relevant inventory parameters required to generate a dataset with Sphera's Agricultural LCA Model. The table below provides a summary overview of this chapter, while each subchapter explains the specifications in depth with more detail.

Table 1: Overview on key inventory parameters and data sources

Inventory parameter	Unit	Data source[1]	Chapter
Crop yield for main- & by-products	kg crop product/ha cultivated	FAOStat	3.1.1
Nutrient contents of harvested product	kg content/kg crop product	USDA Crop nutrient tool	3.1.2
Fertilizer application	kg fertilizer product/ha cultivated	IFStat, OECD agricultural indicators, organic fertilizer calculated based on nutrient balance	3.2
Field emissions	n.a.	Based on IPCC 2019	3.3
Land use and land use change emissions	kg CO_2/ha cultivated	LUC tool based on PAS 2050 and FAO STAT land use data	3.3.2
Emissions from crop residues	n.a.	Based on IPCC 2019 with default factors	3.3.4
Active ingredients	kg active ingredient/ha cultivated	PEST CHEMGRIDS database	3.4
Irrigation applied to meet crop water requirement	m^3/ha cultivated	New values from University of Twente	3.5
Diesel consumption	l diesel/ha cultivated	Reference value (e.g. KTBL) multiplied with energy use intensity (FAOStat)	3.6
Soil erosion	kg soil/ha cultivated	Values from the JRC database	3.3.3
Biological nitrogen fixation (if applicable)	fraction of N in harvested product	Values from meta study	3.2.3
Rice methane emissions (paddy rice fields only)	kg CH_4/ha cultivated	FAOStat	Part 1

(1) full references are provided in the respective chapter

3.1. Crop specifications

3.1.1. Crop yield

Input data for crop yields were derived from the statistical database of the FAO (FAO, FAOstat - Food and agriculture data, 2022). To ensure consistency with the reported fertilizer application rates (see section 3.2), the reference year of the reported fertilizer use was applied to the yields as well. The current reference years therefore range from 2017 and 2019.

Table 3-2: Reference years

Update reference period Sphera	Reference years for yield and fertilizer data
2024	2017-2019

The FAO is an agency of the United Nations that has set its goal to achieve food security and defeat hunger. In total, the FAO works in over 130 countries worldwide. The statistical section of the FAO is called FAOStat and provides free access to food and agriculture data for over 245 countries and territories, from 1961 to the most recent year available. Yields for crops that are not included in the FAOStat database have been derived according to the data collection principles explained in chapter 2.

3.1.2. Crop contents

For several calculations performed during the creation of new datasets, crop characteristics are required. These include:

- N, P_2O_5 and K_2O content
- Water content
- Carbon content
- Energy content

For the nutrient contents, the "Crop Nutrient Tool" provided by the USDA and NRCS has been used. The Crop Nutrient Tool delivers approximate amounts of N, P_2O_5 and K_2O that are removed by the harvest of agricultural crops (USDA, 2021). The data is based on averages from various sources, which can be accessed at https://plantsorig.sc.egov.usda.gov/npk/NutrientSources.

The above-mentioned link also contains the average moisture content of the products, which are reflected in the dataset names and in the reference flow characteristics.

The second choice of retrieving proxy data was the ECN Phyllis database (TNO, 2022), specifically applicable for carbon content of the crops. Included values originated from literature data from the technical university in Wien and ECN biomass analyses. This database has been expanded over the years since its publication in 1999. The ECN classification is an "evolving scheme based on a mixture of plant physiology and practical considerations" (TNO, 2022). This database was used to estimate nutrient contents which were not available in the Crop Nutrient Tool.

3.1.3. Price

In case of allocation procedures included in the datasets, economic allocation has been applied as default. The model used for the calculation can consider any monetary unit, therefore enabling the use of country-specific prices for each crop from country-specific sources. As no single source for agricultural commodity prices, including by-products, could be identified, country specific market sites were used. Generally, the model can reflect further allocation procedures, e.g. nutrient contents as described above.

3.2. Fertilizer application

In 2022, the International Fertilizer Association (IFA) has released a new datasets with global data for fertilizer use by crop and by country (Ludemann, Gruere, & Heffer, 2022). This dataset is based on a survey of experts and provides information on how much inorganic fertilizer (referred to as “fertilizer”) is applied to different crops at national levels:

- It provides the total amount of N, P_2O_5 and K_2O applied per crop in kilograms per hectare (kg/ha).
- It contains data for 73 countries, representing over 90% of global fertilizer use. The countries are grouped into seven regions: Africa, Asia, Europe, Latin America, North America, Oceania and West Asia
- The reference year is not same for all countries. It ranges from 2017 to 2019, with 2018 being the most common year. The reference year reflects the latest available data for each country at the time of the survey.
- Organic fertilizers are excluded from the dataset. Only mineral fertilizers (including straight fertilizers, compound fertilizers and blends) are considered.
- The dataset is based on the "best available source" according to the assessment of IFA and its network of experts. The sources include official statistics, industry data, research reports, expert estimates, and other publications.

The dataset is available in .csv format and can be downloaded from the IFA website. The dataset is accompanied by a data descriptor article published in Scientific Data, which provides more details on the methodology, data quality and limitations of the dataset (Ludemann, Gruere, & Heffer, 2022). For all crop-country-combinations (CCC) for which IFAStat data is available, the application rates have been used as reported. For CCC where no data was available from IFAStat, an approximation approach was developed, which is described in the following section. This approach also applies to wider CCCs that are reported only as groups in the IFA dataset (e.g. “fruits”). The underlying reason that calculated fertilizer application rates were used as proxies is because the reported crop groups were too broad and heterogeneous (i.e. they summarize many different crops with very different yield and cultivation patterns). Therefore, they are not suitable to derive an application rate for a single crop contained in the group (e.g. using the values of "fruits" for "grapes").

3.2.1. Proxies for missing crop country combinations

To estimate fertilizer application rates of crops for which data from the IFAStat is not directly available, the following stepwise approach was applied:

- The nearest crop(s) in the same country (=botanically related to the target group) were selected. For example, if the target crop is triticale, the nearest crops could be wheat or barley.
- The calculated nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE) for the nearest crop(s) from IFAStat (see above) was identified (using nutrient contents from USDA, see section 3.1.2). If more than one crop was selected, the average NUE and PUE values were calculated. Where no botanically related crop for which specific data was available could be identified, the country average NUE and PUE was calculated
- The N, P_2O_5 and K_2O contents in the target crop were identified based on the USDA crop nutrient tool or other databases (see section 3.1.2)[1].
- The yield of the target crop was multiplied with the N, P_2O_5, and K_2O contents to obtain the nutrient uptakes with the harvested crop.

[1] Some sources may give phosphorus (P) and potassium (K) content instead of P_2O_5 and K_2O content. In that case, the conversion factors 2.29 for P and by 1.2 for K were used to convert to P_2O_5 and K_2O, respectively.

- The nutrient uptake of the target crop was divided by the NUE and PUE of the nearest crop(s) to obtain a proxy for mineral fertilizer application rate. Potassium use efficiency (KUE) was assumed to be 1 (application equals uptake[2]).

3.2.2. Estimates for organic fertilizer rates

The IFAStat based approach described above provides mineral fertilizer application rates for different crops and countries, but this data does not include organic fertilizer use. Organic fertilizer rates can be significant, especially in countries with high animal densities or low mineral fertilizer application rates. By using yield data from FAOStat and nutrient contents from USDA to calculate nutrient uptake with the harvested crop and comparing these with the mineral fertilizer application rates, the nutrient balances are often close to zero or even negative.

The OECD publishes nutrient balances (for N and P) for many countries (OECD, 2022). The underlying assumption for estimating organic fertilizer rates is the difference between the calculated nitrogen balance based on mineral fertilizer and the reported OECD nutrient balance. The following stepwise approach was used to estimate organic fertilizer application rates:

- N and P inputs from mineral fertilizer for each crop-country-combinations (CCC) are calculated, using the IFA data on fertilizer use by crop (FUBC).
- For each CCC, N and P outputs from crop uptake are calculated, using the FAO yield data and USDA data on nutrient content of harvested crops (as described above).
- N and P outputs are subtracted from the N and P inputs to obtain the N and P balance from mineral fertilizer for CCC. This balance represents the surplus or deficit of nutrients from mineral fertilizer use.
- The N and P balance from mineral fertilizer are compared with the N and P balance reported by the OECD for each country[3].
- If the N or P balance from mineral fertilizer is greater than or equal to the OECD reported balance, it is assumed that there is no organic fertilizer use for that crop and country, and the mineral fertilizer application rates are as reported (or calculated).
- If the N or P balance from mineral fertilizer is less than the OECD reported balance, it is assumed that there is organic fertilizer use for that crop and country, and the amount of organic fertilizer applied is calculated as the difference between the OECD reported balance minus the balance calculated based on the IFA data.
- If a country is not available in the OECD data, the global average N surplus (36.5 kg N/ha) and P surplus (6.0 kg P_2O_5/ha) were used as proxies for the OECD reported balances.

The OECD nutrient balances are not crop-specific. The calculation of organic fertilizer rates is therefore over-simplified, however this methodology provides some estimates where no additional data or consistent methodologies are available. Some more reflections on the chosen approach:

  - The FAO reports average organic fertilizer rates as N per ha, but not crop specific. Simply adding these to the mineral fertilizer application rates without any consideration of the N balance will certainly lead to less realistic results than the approach described above.
  - No consistent way could be suitably identified to specify for which CCCs the application of organic fertilizer should be excluded. However, for CCCs where organic fertilizer is less relevant, the reported mineral fertilizer application rates are expected to lead to N balances closer to the reported

[2] KUE values often varied between positive and negative in the same country so it was difficult to build reliable averages. At the same time the values only impact provision impacts (there are no emission impacts from potassium), hence this simplified process was implemented until appropriate data may be available to refine this approach in the future.

[3] The OECD balance was used excl. athmospheric deposition

national OECD averages, and therefore the approach described above will lead to application rates for organic fertilizer that are zero or close to zero.

- The approach ensures that the nutrient intensity of a country is reflected in the datasets, and that negative or unrealistically low N surpluses for crops in countries that usually have high nutrient surpluses are avoided.

3.2.3. Biological nitrogen fixation

An exception for nitrogen fertilizer applications are legume crops:. Legumes can form a symbiotic relationship with atmospheric nitrogen-fixing soil bacteria, called rhizobia. The methodology used to compile the inventories considers that only a fraction (i.e. <100%) of the total nitrogen in legumes is provided by BNF, using plant specific BNF-values for legumes based on values from (M.B. Peoples, 2009), generally in the range of around 40% to 70%. The difference between the amount of N crop uptake and BNF is assumed to be provided by mineral fertilizer application. If the IFA reported mineral fertilizer application rates are larger than the difference between nutrient content in the harvested product and BNF, the rates are used as reported. If the reported rates lead to a deficit in the N-Balance, the difference is compensated with additional fertilizer application according to the N-Balance approach suggested in the PEF-method (see Part 1 of this documentation, Part 1: Model & Methods).

3.2.4. Type of fertilizer

Once the application rate is established, the types of fertilizers that are applied to the field were identified from IFAstat. A 5 year average from the data on application of nitrogen, phosphate and potassium fertilizer products containred in IFAstat was used.

The consideration of multinutrient fertilizers in the IFAstat is the main challenge to overcome to calculate the correct amounts of total N, P_2O_5 and K_2O applied to the field. Hence, the retrieved data is processed with an Excel-based tool dedicated to configure the correct combination of fertilizer applied matching to the amounts as described in the previous chapter. The process of identifying the fertilizer types is described stepwise below:

- First, the application rates (see section 3.2) are sorted by amount, i.e. from smallest (limiting), medium and largest (maximum) application amount of nutrient (N, P, K) per CCC.
- Next, the fertilizer type is assessed for the smallest to largest nutrient application. The percentage of each specific fertilizer type within this nutrient category in relation to the total amount applied is calculated.
- Fertilizer types that represent <10% of the fertilizer use in the respective nutrient category and country are not considered

Following considerations are applied in order to correctly consider the total amounts of N, P_2O_5 and K_2O applied to the field and avoid double-counting:

- No fertilizer type is used twice, this also applies to multinutrient fertilizers for simplification reasons (since otherwise they would appear at least twice, e.g. AP in nitrogen and phosphate nutrient category)
- In case a multinutrient fertilizer (e.g. NPK 15-15-15) has already been applied in one nutrient category (e.g. in the nitrogen nutrient category) then the associated amount of other nutrients contained in the fertilizer (e.g. phosphate and potassium) is subtracted in the other nutrient category

In the background of the Sphera's Agricultural LCA Model the fertilizer datasets are available within the MLC database are used for the fertilizer types as identified above (see Part 1, Annex4) .

3.2.5. Background datasets used

An overview of background datasets used in Sphera's Agricultural LCA model is provided in Part 1 of the documentation series (Part 1: Model & Methods).

3.3. Field emissions

3.3.1. From fertilizer (emissions factors)

For more information regarding emission modelling please see Part 1: Model & Methods.

3.3.2. Land Use Change

For land use change values, Sphera has created its own land use change tool, which updates annually. It follows the recommendations of the European Commission, using the PAS 2050 methodology (BSI, 2012). This is also in accordance with the GHG Protocol Land Sector and Removals Guidance Draft from 2022 (GHG Protocol, 2022) (e.g., see chapter 17 of the guidance).

In summary, the following data has been retrieved for the datasets:

- IPCC Guidelines 2006 & 2019:
    - Biomass carbon stocks
    - Soil organic carbon stocks
    - Dead wood and litter carbon stocks
- Forest Resource Assessment:
    - Forest vegetation carbon stocks
- FAOStat:
    - Area harvested
    - Forest Land
    - Land under permanent meadows and pastures

The last update of the LUC tool was performed in 2023, including a comprehensive review and quality assurance process for the set-up of the calculations. The tool is expected to be updated every year. For future updates of datasets, the newest available values shall be implemented. Currently, the latest available reference years are as follows:

- Forest Resource Assessment data: 2019
- FAOStat data: 2020

3.3.3. Soil Erosion

For the soil erosion values, GIS data has been extracted from the JRC work (Joint Research Centre, 2019). The aggregation of values is available on country and regional level. For the datasets, the aggregation on country level has been used. Unit of the data is kg soil/ha cultivated area, time reference is the year 2019. The methodology only considers 20% of those values, to reflect the soil erosion that is occurring due to surface water erosion (Prasuhn, 2006)[4]. For perennials this value has been adjusted to only consider 10% of the value as explained before, in order to reflect the improved soil protection through permanent cover

[4] Most eroded soil is being deposited on other patches of land downhill as colluvium, and not entering water bodies

and a more extensive root system compared to annual crops. Soil erosion contributes emissions of phosphorus and heavy metals to water, see Part 1 of the documentation.

3.3.4. Crop Residues

Information about crop residue specifications have been derived from the IPCC Guidelines, Volume 4, chapter 11, table 11.1A (IPCC, 2019). For crops that are not included in the IPCC specifications, individual literature values have been used instead.

3.4. Active Ingredients

For the application of active ingredients, GIS data has been extracted from a study, which developed global gridded maps of the top 20 crop-specific pesticide application rates from 2015 to 2025 (F. Maggie et al., 2019). The following the availability of crop (classes) in the comprehensive database are listed:

Dominant crops

- Alfalfa
- Corn
- Cotton
- Rice
- Soybean
- Wheat

Aggregated crop classes

- OrgGra (=Orchards & Grapes)
- PasHay (=Pasture & Hay)
- VegFru (=Vegetables & Fruits)
- Other Crops

The reported crop specific pesticide applications have been aggregated to country level. The mapping of crops to the different crop classes can be found in Annex 1. The emission modelling of pesticides is described in the first part of the documentation (Part 1: Model and Methods).

3.5. Irrigation

3.5.1. Amount of water irrigated

The university of Twente has developed a new method and updated values for water consumption of crops (Mialyk, et al., 2023), which are used to specify irrigation water and rain water consumption of the crops. Water consumption from capillary rise is included as well, as specified in the mentioned database (Mialyk, et al., 2023).

Application of nitrogen through irrigation, so called fertigation, has been set to zero as a default for all datasets, since all fertilization processes are considered in the standard procedure of applicating mineral fertilization to the crops. Information about the fertilization process can be found in section 3.2.

3.5.2. Irrigation pump specifications

The energy requirement for irrigation is estimated based on the amount of water irrigated (see above) and a pump model. The pump model is a standard MLC dataset, the documentation can be found online[5].

Information about the share of irrigation water extracted from groundwater, data from AQUASTAT, FAO's “Global Information System on Water and Agriculture”, has been extracted (FAO, 2022). For this, the lift specified below is assumed. For surface water, a lift of zero is applied, see below.

As there is no consistent data regarding the use or share of electricity and diesel for irrigation pumps worldwide, a conservative “worst case” approach has been applied. This approach assumes a share of 100% diesel is used irrigation pumps.

Further defaults are listed down below (see pump model documentation for details):

- Ratio irrigation efficiency = 1
- Lift - groundwater table = 11.5m (based on (Y. Fan, 2013))
- Lift - surface water = 0
- Nominal operating pressure = 3
- Power unit efficiency = default 0.9 for electricity and 0.4 for diesel
- Power unit efficiency = default 0.9 for electricity and 0.4 for diesel
- Ratio pumping efficiency = 0.8

3.5.3. Water scarcity (AWaRe)

The WULCA working group, which focuses on water use assessments in the LCA community, has published the AWaRe-values (=Available Water Remaining). The AWaRe characterization factor is described as “the normalised water availability minus the demand of humans and aquatic ecosystems, [...] relative to the area” (WULCA, 2019). The aggregated country values are used to consider water scarcity impacts. For more details about water assessment in the LCA FE software and in the MLC background datasets see Sphera’s Introduction to Water UseAssessment 2022[6].

3.6. Diesel Consumption

There is no consistent global data source for fuel consumption or agricultural machinery use for different crop country combinations. Therefore, it was decided to estimate diesel consumption based on an approach from (A. Roches et al., 2010), whom have been creating a modular methodology for extrapolating LCI data of crops. The basic principle outlined in this publication is that a reference value for a specific crop country combination is determined. This reference value is then modified to estimate impacts for the same crop grown in other countries by applying correction factors based on cultivation intensity. The modification procedure is specified for different sub-compartments of a cultivation system including machinery use. However, the principle approach was modified in the presented assessment, which is described in the following. In summary, the basic calculation is as follows:

*Diesel consumption for crop country combination (xy) = Reference diesel consumption for crop (x) in country (x) * correction factor based on intensity of machinery use in country (y)*

[5] https://sphera.com/2022/xml-data/processes/15903a91-f76f-4535-aaf3-43d89962cfe4.xml
[6] https://sphera.com/wp-content/uploads/2022/02/Sphera Water LCI Modelling Assessment 2024

3.6.1. Reference crop specific fuel consumption

Initial fuel use values (l/ha) have been retrieved by the following hierarchy:

1. 'Verfahrensrechner Pflanze' (KTBL, 2017) for specific crops and crop categories
2. Reference values from literature research

3.6.2. Intensity based correction factors

To calculate country specific correction factors for fuel use intensity, data from FAOStat has been extracted for the following categories:

1) Energy use (Gas Diesel) in agriculture (Terajoule per country)
2) Area harvested for crops and livestock products (Hectares)

These values were used to calculate the energy use per ha. The energy use (per ha) in the country of the reference value is then divided by the energy use (per ha) of the target country. The square root of this quotient (result of this division) is used as the intensity factor to scale the reference fuel consumption. The square root is applied because the enery use values from FAO stat are not directly convertible into diesel use by hectare, and the impact differences reported were considered to be too large to applied directly. The application of the square root allowed to use the FAO STAT data as intensity factor while keeping the differences between countries in a realistic range (compared to using the quotient directly).

3.7. Additional default data

In the following, default assumptions that are applied to all datasets are listed:

- Seed and planting material input for annual crops: 200kg/ha (default value due to low relevance of parameter)
- No consideration of nitrogen contained in irrigation water (see 3.5)
- Transport distance for agricultural inputs: 100km
- Heavy metal input with mineral fertilizers is considered, (see Part 1)
- Plant uptake of heavy metals in crops is set to zero as default according to approach (a) in the PEF Method (PEF Method 2021)
- N deposition is not considered in the N-Balance calculation and the emission modelling (the related emissions are considered to occur irrelevant of the production system[7]
- Nitrate emission modelling is based on N-Balance approach (see Part 1 and PEF Method 2021)

[7] I.e. it is assumed to be applicable even if the land is not under agricultural use (i.e. nature/set aside land), and therefore its impact are considered neutral.

4. Limitations and use advice

Due to variable environmental conditions and high site heterogeneity, agricultural systems are very complex production systems to model in life cycle assessments. The below listed are some reasons behind this complexity but not limited to:

- The variety of different locations
- Small scale soil variability within locations
- The large number of farms
- The variety of agricultural practices
- No determined (or at least controlled) border to the environment (hence severe limitations to measure most emissions across large, open surface areas and in deeper soil layers)
- Complex and indirect dependence of the output (harvest, emissions) from the input (fertilizers, location conditions)
- Variable weather conditions within and between different years
- Variable and dynamic pest populations (insects, weeds, disease pathogens)
- Different and changing crop rotations
- Land use and land use change
- Water use with variable consumption pattern and irrigation techniques

As described in section 1, the goal and scope for the development of the presented agricultural LCI datasets is to generate generic country specific crop cultivation datasets, with consistent data and transparent documentation. The datasets can be used as background data in LCA studies or in scope 3 emission reporting. For this purpose, the datasets represent country averages. On input level many of the required datapoints are only available on country level as well. However, the variation of cultivation systems and the related environmental impacts within a country can be very large due to the factors listed above. The datasets should therefore mainly be used as background datasets. **In cases where an agricultural system represents the foreground system of an assessed product or the main impact contributor to it, also if the cropping is not operated by the producer, the presented contry-level/generic input data cannot substitute supply chain specific information based on primary data.**

In addition to this general statement, specific limitations of the used input data should be considered:

- **Yield data**: while the FAO database (see section 3.1.1) is the most recognized source for yield data, it has been observed, that the data is may change in retrospective for various reasons.
- **Temporal representativeness**: statistical data is often published with long delays. As described in section 3.2, the most recent fertilizer use statistics refer to the years 2017 – 2019, i.e. 5 years back from the publication of these datasets. While this is still the most recent data and there are usually no disruptive changes in agricultural systems, especially not on country level as a total, this is a clear limitation in temporal representativeness. In addition, the fertilizer statistics refer to a single reference year. Yield data has been matched accordingly. Usually, it is preferred to work with multiples year averages, which was not possible in this case.
- There is no crop specific comprehensive data on **organic fertilizer application** rates available currently, despite the large relevance of this fertilizer in nutrient supply. The comparison of reported N balances in literature and statistical databases with the N balances resulting from the IFA data also highlight the necessity to consider organic fertilizer. Therefore, the presented approach to use the country average N-Balance based on OECD data (see section 3.2.2) can be considered reasonable, with a clear advantage over excluding organic fertilizer input or using a country

average organic N input. However, the numbers are subjected to high uncertainty and the results should be interpreted with care.

- The **impacts of provision of fertilizer** can vary between different countries of production. Currently, not all of the main fertilizer producing countries are available in Sphera's MLC database (see documentation Part 1, Annex 4). While the impacts of the available datasets seem to be in line with published data, the missing regional granularity is also leading to uncertainty of the overall results.
- Calculating the N-Balance to estimate organic fertilizer application, mineral fertilizer application for crops with missing data in fertilizer statistics and nitrate emissions requires information on the **nutrient contents** of crops. The crop nutrient content can be variable between years and regions as well as variants and breeds, however, currently such granular data is not available. Using a single average per crop across regions is a simplification, which also contributes to uncertainty of the related estimated input parameters.
- **Pesticide application** data is difficult to obtain. The presented approach to use the PEST-CHEMGRIDS database (see section 3.4) allows to get consistent crop and country specific data. However, only a limited set of specific crops is available, so that application rates from crop categories or related crops were used as proxies for other crops. In addition to that, the used values are modelled based on historic trade statistics and crop growth models. Primary data collection can result in a very different crop protection profile. In addition, using generic emission factors to specify the amounts of pesticides that reach the different environmental compartments is also a large simplification (and updates are currently already discussed in the LCA community). Therefore, the impact assessment results for ecotoxicity of the presented datasets are particularly associated with uncertainty.
- Many assumptions and simplifications where necessary to estimate the **energy consumption for irrigation** (see section 3.5.2). While a differentiation between ground water and surface water sources is considered, neither ground water levels nor more granular irrigation techniques are differentiated. Also, it could not be reliably differentiated where systems are operated by electricity or by diesel. All this in combination leads to large uncertainty of the impacts from irrigation energy consumption.

Sphera is constantly reviewing options for further improvements to reduce the associated uncertainties and resulting limitations, and new data will be considered in future updates if available. However, it should be noted that these limitations are not specific to the datasets described, but affect work with generic agricultural data in general. While Sphera is confident that the best available data was used in relation to the goal and scope of the data development as described above, this should serve as a motivation to use more granular, supply chain specific primary data wherever possible.

Please contact the Sphera team if you have any questions or comments, if you have detected an error or if you would like to discuss options for more detailed assessments.

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Annex 1 – Mapping of crops

Table apx 1: Mapping of crops to crop classes according to (F. Maggie et al., 2019)

Vegetables & Fruits (VegFru)	Orchards & Grapes (OrcGra)	Pastures & Hays (PasHay)	Other Crops
Artichokes	Almond	Cabbage (forage)	Agave
Asparagus	Apples	Carrots (forage)	Anise
Avocados	Apricot	Forage*	Areca
Beans (string, broad, green)	Cherries	Pasture	Bambara
Beats (forage)	Chestnuts	Rye (forage)	Barley
Beets	Citrus	Sorghum (forage)	Buckwheat
Berries (Blue-, Cran-, Cane-, Rasp-, Straw- and Gooseberries)	Dates	Swede (forage)	Canary seed
Cabbage	Figs	Vegetable (forage)	Carob
Carrots	Grapefruit	Vetch	Cashew
Cauliflower	Grapefruit		Castor
Chicory	Hazelnut		Chili
Cucumbers	Kiwifruit		Cinnamon
Currants	Lemon		Clove
Eggplant	Limes		Clover
Fruits*	Mangos		Cocoa
Garlic	Nuts (Nutmeg, Brazil, Cashew, Groundnut, Walnut, Nuts*		Coconut
Gingerroot	Olives		Coffee
Herbs (Spices*)	Oranges		Coir
Legumes*	Papayas		Fibres*
Lentil	Peaches		Flax
Lettuce	Pears		Fonio
Melons	Persimmons		Grass*
Non-citrus fruits (e.g. Banana)	Pistachios		Green corn
Okra	Plums		Gums
Onions	Prunes (e.g. sour cherry)		Hemp
Peas (Chick-, Pigeon-, green and sweat pea)	Stone-like fruits*		Hempseed
Peppers			Hops
Pineapple			Jute
Plantain			Jute like fibre
Potatoes			Kapok fibre
Pulses*			Kapok seed
Pumpkin			Karite

Root tubers (Cassava, Yautia, Yam, Roots*)			Kola nut
Spinach			Linseed
Sweet potato			Lupin
Tomato			Mate
Turnips (forage)			Millet
			Mixed Grain
			Mixed Grass
			Mushroom
			Mustard
			Oats (cereals*)
			Oil palm
			Oilseed (forage)
			Oilseeds*
			Peppermint
			Pimento
			Popcorn
			Poppy
			Pyrethrum
			Quince
			Quinoa
			Ramie
			Rapeseed
			Rubber
			Rye
			Safflower
			Sesame
			Sisal
			Sorghum
			Sugar* (-beets, -cane)
			Sunflower
			Taro
			Tea
			Tobacco
			Triticale
			Tropical*
			Tung
			Vanilla

*not elsewhere specified