the big CLIMATE DATABASE

Version 1

Methodology report

Report
Published: February 2021 by CONCITO
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Funded by: Salling Foundations

2.-0 LCA consultants

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Preface

This report is prepared for Concito by 2.-0 LCA consultants January 2020 to February 2021. The report is the technical documentation of The Big Climate Database ("Den store klimadatabase"), which is published by Concito and funded by the Salling Foundations. It should be noted that all linked LCA activities and their flows can be accessed on the webpage: http://denstoreklimadatabase.dk/

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When citing this report, please use the following citation:

Schmidt J, Merciai S, Muñoz I, De Rosa M, Astudillo M (2021). The Big Climate Database v1 – Methodology report. 2.-0 LCA consultants, Denmark

List of abbreviations

List of Acronyms

Acronym	Description
CH_4	Methane
CO_2	Carbon dioxide
dLUC	Direct land use changes
FCR	Feed conversion rate
iLUC	Indirect land use changes
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LUC	Land use changes
N_2O	Dinitrogen monoxide

Countries and regions

The Big Climate Database follows the same geography as the EXIOBASE database. Below the countries and regions in EXIOBASE are listed.

Country code	Country name
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
GB	United Kingdom
US	United States
JP	Japan
CN	China
CA	Canada
KR	South Korea
BR	Brazil
IN	India
MX	Mexico
RU	Russia
AU	Australia
CH	Switzerland
TR	Turkey
TW	Taiwan
NO	Norway
ID	Indonesia
ZA	South Africa
WA	Rest of World (RoW) Asia and Pacific
WL	Rest of World (RoW) America
WE	Rest of World (RoW) Europe
WF	Rest of World (RoW) Africa
WM	Rest of World (RoW) Middle East

1 Introduction

This report documents the data and methods used to produce The Big Climate Database. The database includes detailed data for 500 food items at retail in Denmark. The database is among the largest and most complete of its kind.

The development of The Big Climate Database has been funded by the Salling Foundation, which is part of Salling Group, who is the largest retail group in Denmark. The modelling has been performed by 2.-0 LCA consultants in collaboration with CONCITO.

Food at the Danish market involves import of crops, animals and processed food items from all over the world. Therefore, as part of the development of The Big Climate Database, all crops and all animal categories in all countries in the world have been modelled as part of the current study. This also means that the current version of the database can easily be expanded to cover 500 food items at retail in any other country in the world.

Key for the development of the database has been consistency, completeness, flexibility and updatability. Consistency means that the same modelling principles and emissions models have been used across all crops, animals and food processing industries in all countries in the world. Completeness means that no flows have been cut-off in the life cycle inventories. This has been achieved by using EXIOBASE, which is a multi-regional hybrid input-output database, as background database. Flexibility means that any calculation module can be revised or replaced, and that the number of included crops, animals, food processing industries, countries, years etc., can easily be expanded. Updatability means, that the entire model can easily be populated by the newest data from global databases and thereby be updated to a new year.

2 Goal and scope definition

This chapter describes the overall purpose and scope of The Big Climate Database, and hereunder the applied overall methods. Specific methods used in individual life cycle stages, e.g. crop cultivation, animal production and food manufacturing, are described in dedicated chapters.

2.1 ISO 14040/44

The LCA is carried out in accordance with the ISO standards on LCA: ISO 14040 (2006) and ISO 14044 (2006), with the following exceptions: The LCA does not include Life cycle interpretation phase, the study has not been subject to a critical review. According to the ISO standards, an LCA consists of four phases:

1. Definition of goal and scope
2. Life cycle inventory (LCI)
3. Life cycle impact assessment (LCIA)
4. Life cycle interpretation

The goal and scope phase of the LCA is documented in the current chapter. The first phase includes description of the purpose of the study, definition of the functional unit, an overview of the applied methods and an overview of the relevant processes (system boundary). This also includes important methodological choices affecting the other phases of the LCA, e.g. the system boundaries affect the data to be collected in phase 2, and the method used for LCIA affects the results calculated in phase 3.

The second phase of the LCA, which includes data collection and modelling of the product systems of each food item is documented in chapter 3 to 10.

The third phase includes the presentation of results. The results are presented on the webpage: http://denstoreklimadatabase.dk/

2.2 Commissioner of the study

The Salling Foundations have contracted Concito with 2.-0 LCA consultants as subcontractor for undertaking the current study.

2.3 Purpose of the study

The purpose of the study is to provide climate information for a large number of food items at the Danish market. The goal is that this information can be used to affect consumers, catering, restaurants and retail in their choices of diet and meal preparation in a more climate friendly way and thereby contribute to significantly reduce GHG emissions.

The Salling Group, who in involved in commissioning the study, is the largest retail company in Denmark. The Salling Group intends to using the climate information in the database in their efforts on reducing GHG emissions. Further, the database is made public, enabling consumers, companies, public organisations and NGO's for also making use of the data.

2.4 Included food products and datasets

The Big Climate Database includes several thousands of crop cultivation, animal production and food processing datasets. However, final results are currently only extracted for 500 packaged food products at retail.

The database provide the basis for creating many more food items by combining the included crops, animals and food processing activities using different recipes. This option is possible in the SimaPro version of the database that will be available.

Below, a brief description of the included datasets in the database is presented. Inputs which are not covered by the datasets listed below are modelled using the EXIOBASE v3.3.16b2 (hybrid) version. The database includes **12,178 inventoried datasets** divided on.

- Food products at retail in Denmark (500 datasets)
- Crop production (3256 datasets)
- National crop markets (5244 datasets)
- Animal production (402 datasets)
- National animal markets (1900 datasets)
- Food processing activities (447 datasets)
- Packaging constellations (71 datasets)
- Retail activities (3 datasets)
- Various background datasets (355 datasets)

Food products at retail in Denmark

The choice of which food products to be included in the database is made in collaboration between Salling Foundation and Concito. The included food items are chosen to represent the most sold food items in the Danish retail market, and they have been identified based on sale statistics provided by the Salling Group.

The database include 500 food items. These are distributed on the following categories. The number of included food items per category is indicated in brackets.

- Vegetables (56)
- Fruits (27)
- Meat/poultry (62)
- Seafood (51)
- Milk/eggs/substitute products (31)
- Cereal/grain/pulse products (22)
- Fruit/vegetable products (75)
- Oils/fats edible (4)
- Bread/bakery products (34)
- Prepared/preserved foods (61)
- Seasonings/preservatives/extracts (32)
- Candy/sugar products (13)
- Beverages (32)

Crop production

The crop production module includes all crops included in the FAOSTAT database (FAOSTAT 2020). This include 185 crops in 245 countries. The 245 countries in FAOSTAT have been aggregated to match the 43 countries + 5 rest-of-world regions in the EXIOBASE database (see section 3.1).

National crop markets

To obtain data on, where the demand for crops in a certain country is sourced from, national crop markets are established. Crop markets are established for the 185 crops in FAOSTAT and for the 43 countries + 5 rest-of-world regions.

Animal production

The animal production module includes all 12 animal herds in 245 countries included in the FAOSTAT database (FAOSTAT 2020). The 245 countries in FAOSTAT have been aggregated to match the 43 countries + 5 rest-of-world regions in the EXIOBASE database (see section 3.1).

National animal markets

To obtain data on, where the demand for animals in a certain country is sourced from, national animal markets are established. Animal markets are established for the 12 animal herds in FAOSTAT and for the 43 countries + 5 rest-of-world regions.

Food processing activities

All involved food processing activities to produce the 500 food items are included. This involves 447 different food processing activities. Only one food processing activity is established per food type to be produced, i.e. the most relevant sourcing country to food demand in Denmark has been selected. By default the location of the food processing is set to be Denmark. But for food products, which are predominately produced outside Denmark, another country is chosen, e.g. winemaking is in Italy, olive oil production is in Spain, and palm oil production is in Indonesia etc.

Packaging constellations

71 representative packaging types have been defined. The included packaging types have been defined adhoc by the project team. All packaging manufacturing is assumed to be located in Denmark, where the demand for raw materials link to national markets in Denmark as of EXIOBASE v3.3.16b2, e.g. plastics in Denmark is sourced from Rest of Asia (21%), Netherlands (20%), Germany (13%) etc.

Retail activities

Retail includes all inputs and outputs of the supermarket activity. Three datasets are established for three types of storage: ambient, cooled and frozen.

Various background datasets

A number of additional background datasets have been created. These are created when required activities are neither included in the above mentioned datasets nor in the EXIOBASE database. The datasets include e.g.:

- Fuel and combustion datasets: In EXIOBASE, all relevant fuels are available. But when the fuels are used in e.g. the food processing industry, we also need to include the combustion emissions. The 'fuel and combustion' datasets combine inputs of fuels from EXIOBASE with associated combustion emissions.
- Transport datasets: In EXIOBASE, all relevant data on transport are available. However, the reference flow of the activities is in monetary unit. This is a bit difficult to link to inventories of transport in units of tkm. Therefore, datasets where transport datasets in EXIOBASE are converted to units of tkm are created.
- Data for the rendering industry
- Data for capital goods and services

The most important 'Various background datasets' are described further in chapter 3.

2.5 Functional unit, reference flow and comparisons

The current study includes the development of a database with results on life cycle climate information for 500 food items at retail at the Danish market. As described in section 2.4, the database also includes thousands of other datasets. The reference flow of these datasets is typically 1 kg product at activity gate, except for packaging datasets, which also include end-of-life treatment.

The database does not operate with a functional unit, since this would require a specific purpose of an LCA study. Instead, the climate information for the included foods is provided for a reference flow of one kilo of food at retail.

The database does not provide a direct basis for comparing different foods because the foods fulfil different needs such as satiety, protein and energy needs, stimulation etc. According to Weidema and Stylianou (2020) suggest to using satiety as a central attribute for comparisons of food products, while other properties (such as weight, protein or energy) or weighted averages hereof are suggested to be largely misplaced as part of the functional unit.

The database does currently not include data on satiety for the different food items. Hence, when the database is used for comparisons, it should be ensured that the compared quantities of food items (or meals or diets) represent a relevant substitution or choice. E.g. 1 kg carrots is not comparable with 1 kg beef in 1:1 basis because each kilo of these products provides different satiety.

2.6 System boundaries

The database include all upstream activities for food at retail. Hence, the LCA can be categorized as a cradle-to-gate study, where the gate is at retail.

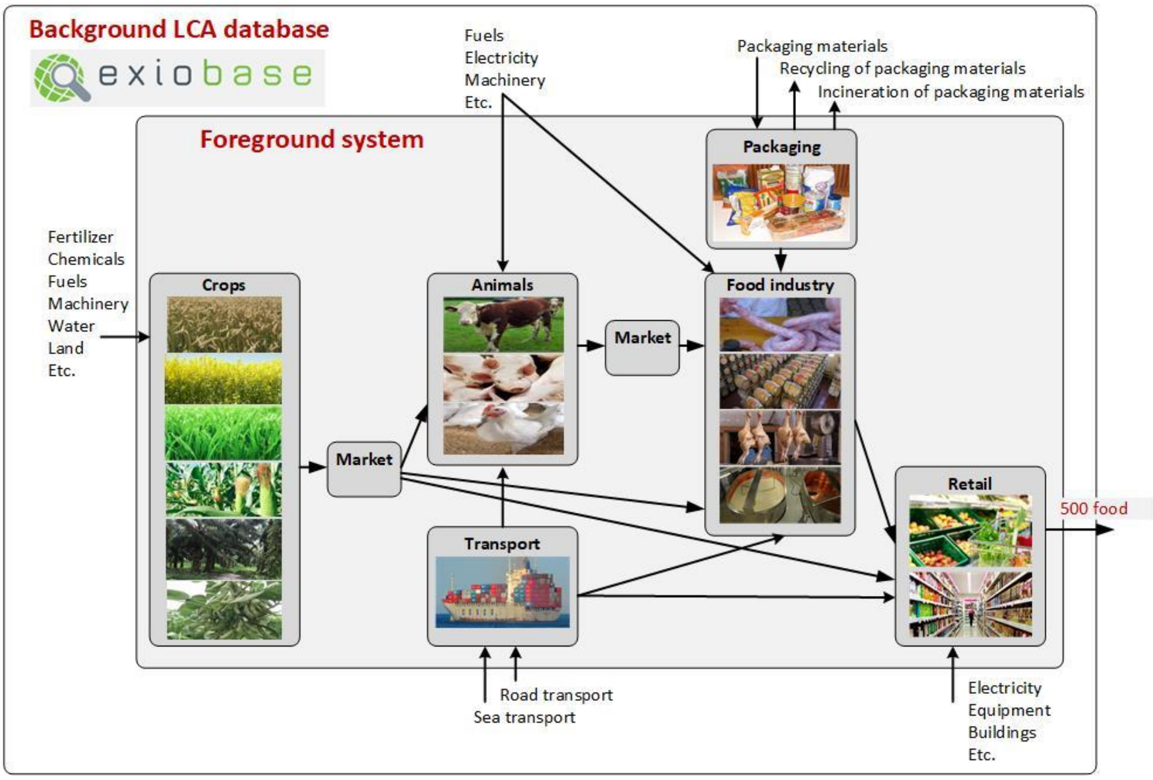

Figure 2.1: Illustration of system boundaries, life cycle stages and foreground/background system.

Life cycle stages

The results include all impacts to the retail gate. If full life cycle impacts on food products is needed, then transport from retail to end use, food storage and preparation, dishwashing and treatment of food waste are to be added to the results provided in the database.

The database includes the following life cycle stages, for which results are specified:

- **Agriculture**
  This life cycle stage includes all emissions from agriculture including upstream emissions from the production of fertiliser, chemicals, fuels, machinery, buildings, services as well as transport of these inputs to agriculture. Further, the substituted productions caused by by-products are included. This refers to e.g. beef (cows, heifers and bulls) from milk cattle, and wool from sheep.
- **Indirect land use changes (iLUC)**
  When activities use land, additional land will be "produced" in the same manner as demand for fertiliser cause production of fertiliser. The following activities use land: crops, animal grassing, forestry, urban area, infrastructure and mining. When an activity use land, this cause expansion of human activities into wild nature as well as intensification of existing productive land (yield increases).
- **Food processing**
  Food processing includes direct emissions from this industry as well as emissions from all upstream activities except agriculture and iLUC: the production of fuels, chemicals, machinery, buildings, services, transport of non-feedstock inputs (transport of agricultural products to food processing is included under the life cycle stage 'transport') and treatment of materials for treatment. The latter includes treatment of wastes as well as processing of residues to animal feed and other by-products, e.g. in the rendering industry. The substituted productions caused by by-products are included.
- **Packaging**
  Packaging includes all upstream emissions from the production of packaging materials as well as downstream emissions from end-of-life treatment of the materials. When the end-of-life includes by-products such as recovered energy from waste incineration and materials from recycling/reuse, the substituted production of heat, electricity and virgin materials are included.
- **Transport**
  This life cycle stage includes the transport of agricultural products to food processing and food products to retail. All other transport is included under the other life cycle stages.
- **Retail**
  Retail includes all direct and upstream emissions from the inputs of fuels, energy, equipment (displays, cash registers, refrigerated counters, freezers, building etc.)

It should be noted that end of life treatment of food packaging is included in the presented results. This is not strictly in line with the cradle-to-gate system boundary of food at retail. The End-of-life of packaging is included to avoid that some certain products, where the majority of the impact is associated to the packaging and where this impact is recovered in a recycling/reuse process, will misleadingly fall out with a very high impact. One example is beer and soft drinks sold in reusable glass bottles. If the glass bottles are not reused, the impact of 1 kg beer would increase from around 0.5 to 1.5 kg CO_2-eq.

Geographical scope

The database includes 500 food products at retail at the Danish market.

The retail stage is purely located in Denmark and it is modelled using inputs of products at the Danish market.

The location of the production of food processing industries is by default assumed in Denmark, while the inputs of agricultural products (crops and animals) are sourced globally from the actual supplying countries. In some cases, where it is obvious that the food processing industry is not located in Denmark, it has been located in the country with the largest supply to Denmark. E.g. wine making is located in Italy, whisky in

Ireland, pasta in Italy, olive oil in Spain, palm oil in Indonesia and Malaysia, soybean meal in US and Brazil etc.

Based on the location of the food processing industry, the sourcing countries of feedstock (crops and animals) is identified as the actual supplying countries of the feedstock. E.g. when whisky is brewed in Ireland, then the input of grain crops is sources from the supplying countries of grain crops to Ireland. As default, the average supplying countries to the countries when the food processing industries are located is assumed. However, for some crops/animals the average supply to a certain country does not reflect the location of the affected supplying countries, when the demand for the crop/animal is changed. The reason for this can be that the market is global and not national, or it can be that the national average market is dominated by by-products. A change in demand for a by-product will not affect the producer, and hence the location of the by-product supplier is not relevant. An example of the latter is the average supply of beef to the Danish market, which is dominated by beef (cows, heifers and bulls) from the Danish milk system, while the supply of the actual affected beef animals from beef herds are located in countries like US, Brazil and Argentina. In this case, the global supply of beef from beef animal herds is used instead of the Danish.

Since the procedure for identifying the location of crop cultivation and animal production described above in principle include all countries in the world, the inventory of all crops and all animal herds is done for all countries in the world.

The geographical resolution of the world is 43 countries and five rest-of-world regions following the same geographical scope as the EXIOBASE v3.3.16 database. The 43 countries include 28 EU countries and after that, countries with the highest GDP are added until 95% of the global GDP is covered. The five rest-of-world regions cover the remaining countries divided on continents: Latin America, Asia and Oceania, Africa, Middle East and Europe.

Temporal scope

The LCA database is intended for providing decision support from now and into the near future (5-10 years). Therefore, it is intended that the results should reflect current and near future changes in demand for food products. This is best fulfilled by using the newest available data, while keeping consistency by not mixing data for different years. It has not been possible to strictly using data only from one specific year (or period). Below, the temporal scope of the different datasets are summarized:

- **Crop cultivation:** Yields, production volumes, fertiliser usages and peat soils are obtained for 2018, while all other data are represented by data from 2011[1]
- **Animal production:** Production volumes, weight gain, milk production, feed uses are obtained for 2018, while all other data are represented by data from 2011[1]
- **Markets for crops and animals:** Trade data are obtained for 2018
- **Food processing industries:** No temporal consistent data are available to model 500 different food items. To reach this high level of detail, the production function of food processing industries have been constructed from many different datasets from different years. However, since the conversion efficiencies of raw materials into food products and the energy efficiencies of food industries are not expected to have changed significantly over the recent decade, these temporal inconsistencies are not expected to introduce significant uncertainties in the results.
- **All remaining activities:** All other transactions in the product system of food production than mentioned above are covered by use of the EXIOBASE v3.3.16 database, which consistently use 2011 as base year.

[1] The base year of the applied background database, EXIOBASE v3.3.16, is 2011.

2.7 Structure of the database

The Big Climate Database includes a number of modules, which are briefly described in section 2.4. Each module is named with a two-letter abbreviation. The modules are the following:

- Ra: Food products at retail in Denmark (500 datasets)
- Ca: Crop production (3256 datasets)
- Cm: National crop markets (5244 datasets)
- Ha: Animal production (402 datasets)
- Am: National animal markets (1900 datasets)
- Fa: Food processing activities (447 datasets)
- Pa: Packaging constellations (71 datasets)
- Ma: Various background datasets, incl. retail (358 datasets)
- Ea: EXIOBASE producing activities (7872 datasets)
- Em: EXIOBASE national product markets (7872 datasets)

Figure 2.2 below illustrates how the different modules of the database are linked. E.g. the activities in the Food products at retail (Ra) module have inputs of products from the following modules:

- Crop markets (Cm): This is inputs of crops to the retail activity (Ra)
- Food products (Fa): This is inputs of food products from the food manufacturing industries to the retail activity (Ra)
- Packaging (Pa): This is inputs of packaging to the retail activity (Ra)
- EXIOBASE markets (Em): This is inputs of EXIOBASE product markets to the retail activity (Ra)

Activities:		500food at retailer	FAO crops	Markets of crops	FAO animal herds	Markets of animals	Food processing	Packaging	Various back-ground activities	EXIOBASE activities	EXIOBASE markets
Number of datasets:		500	3256	5244	402	1900	447	71	358	7872	7344
Products		Ra	Ca	Cm	Ha	Am	Fa	Pa	Ma	Ea	Em
500food at retailer	Ra										
FAO crops	Ca			Cm_Ca							
Markets of crops	Cm	Ra_Cm			Ha_Cm		Fa_Cm		Ma_Cm		
FAO animal herds	Aa					Am_Aa					
Markets of animals	Am						Fa_Am		Ma_Am		
Food products	Fa	Ra_Fa					Fa_Fa				
Packaging	Pa	Ra_Pa									
Various background	Ma	Ra_Ma					Fa_Ma	Pa_Ma	Ma_Ma		
EXIOBASE products	Ea										Em_Ea
EXIOBASE markets	Em	Ra_Em	Ca_Em		Ha_Em		Fa_Em	Pa_Em	Ma_Em	Ea_Em	
Resources	Ext_R		Ca_Ext_R		Ha_Ext_R		Fa_Ext_R		Ma_Ext_R	Ea_Ext_R	
Emissions	Ext_B		Ca_Ext_B		Ha_Ext_B		Fa_Ext_B		Ma_Ext_B	Ea_Ext_B	

Figure 2.2: Database structure. Columns refer to activities and rows refer to product inputs to the activities. The abbreviations in the table: the first two letters refer to the activity and the last to letters refer to the product inputs: [activity_inputs]. The second row from the top indicates the number of datasets (activities) in each module.

The size of the entire model, i.e. the width of the table above is 27,394 datasets of which EXIOBASE activities account for 15,216 activities, i.e. 12,178 activities are created as part of the current project on The Big Climate Database.

2.8 Modelling approaches in Life Cycle Inventory

The study applies a consequential approach to modelling in life cycle inventory in accordance with the international standards for LCA: ISO 14040 (2006) and 14044 (2006) and further defined in Weidema et al. (2009).

Two basic sets of assumptions exist for modelling in life cycle inventory; consequential and attributional modelling (Sonneman and Vigon 2011). Consequential modelling is a cause-effect based approach to the definition of system boundaries in LCA (Sonneman and Vigon 2011), and it is characterised by the modelling of by-products using substitution and by including only unconstrained suppliers in the market mixes[2]. Consequential modelling is used when the study is aimed for decision support and when results are aimed at representing a change in demand for the product at focus in the LCA.

Attributional modelling is a normative approach to the definition of system boundaries in LCA (Sonneman and Vigon 2011), and it is characterised by the modelling of by-products using allocation (though substitution is also sometimes used) and by including all suppliers in the market mixes (both constrained and unconstrained). Attributional modelling is applied with a set of normative rules defined to delimit the activities attributed to the product, either by economic or physical flows.

Consequential and attributional LCAs give answers to different questions. Consequential LCA gives an answer on the question: "*what is the impact of a choice?*" This choice could be to buy or produce a product (compared to not buy or produce the product), or to implement an improvement option. Consequential LCA is relevant when companies/decision makers want to know the impacts of their actions. Attributional LCA gives an answer on the question: "*what are the impacts from that part of the life cycle that it has been decided to include based on the normative allocation and cut-off rules?*" Attributional LCA is relevant when companies want to report their impacts according to consensus-based guidelines/standards, e.g. the EU PEF Guideline.

The general nature of two approaches are comprehensively described in Schmidt and de Saxcé (2016), Weidema (2003) and Weidema et al. (2009). Furthermore, the consequential approach is extensively described with examples here: https://consequential-lca.org.

When substitution is applied, it is important to distinguish between determining (reference) products, by-products and materials for treatment. Reference products are characterised by being the ones for which the demand determine the production volume of the activity, while by-products and materials for treatment are produced regardless of the demand.

There are pros and cons of both consequential and attributional modelling. In view of the authors, the most important ones are listed in **Table 2.1**. The table is based on Schmidt and de Saxcé (2016) and supported by Weidema et al. (2018), Weidema (2018), Weidema (2014), and Weidema and Schmidt (2010).

[2] https://consequential-lca.org

Table 2.1: Pros and cons of consequential and attributional modelling.

Consequential modelling	Attributional modelling
Pros	
• Strives towards identifying the consequences of demanding the functional unit. • Follows ISO 14044 allocation hierarchy, i.e. the highest priority to model by-products is followed. • Based on scientific criteria. • Mass balances are maintained. • Relatively simple to apply consistent modelling of by-products through the product system.	• Seemingly easy: Since the approach is normative, ad hoc choices can be made to exclude complex issues. • Most industry specific LCA and GHG guidelines are based on attributional modelling.
Cons	
• Uncertainties associated with the identification of affected market mixes, i.e. "marginal" suppliers. • Hard to communicate: Since constrained suppliers are excluded, the directly economically connected product chain is not always followed. Negative impacts may be misunderstood.	• Complicated (or impossible) to consistently apply same allocation approach throughout a product system. • Allocated systems do not exist in reality – experts cannot recognise allocated product systems. • Applied market mixes, i.e. "average" suppliers may not represent the consequences of demanding products from the market – because some suppliers are more likely to respond to changes than others. • Most often, the lowest priority to model by-products with regard to the ISO 14044 hierarchy on allocation is followed. • Mass, substance, energy, and other balances are not maintained when allocating. • May lead to misleading results – because of allocation, market averages and normative models. • Hard to communicate: Since allocated product systems do not exist in reality, the modelled system can be difficult to communicate.

2.9 Land Use Changes (LUC)

According to IPCC (2020), 11% of global GHG emissions were relate to land use changes in 2007-2016. A major challenge in modelling LUC is to ascribe the effects to their drivers. The Big Climate Database uses the iLUC model described in Schmidt et al. (2015), which is implemented in EXIOBASE v3.3.16b2 (Schmidt and De Rosa 2028). This is described in detail in 3.2.

2.10 Life cycle impact assessment (LCIA)

The Big Climate Database currently only include impacts on GHG emissions. Expressing climate change as a single impact category measured in CO_2 equivalents means that all GHG-emissions associated with a product are turned into one indicator. This indicatotor is calculated using the Global Warming Potential (GWP100), where different emissions' radiative forcing during a 100 year time horizon is expressed relative to the radiative forcing of CO_2 in the same time horizon. This means that the contribution to climate change from different greenhouse gasses can be expressed in CO_2 equivalents.

The following GHG emissions are included:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Dinitrogen monoxide (N_2O)
- Halocarbons: CFCs, HCFCs, HFCs, PFCs

The characterisation factors, i.e. factors to convert the above emissions to CO_2-eq., follow IPCC (2013). However, for methane these are corrected according to Munoz and Schmidt (2016). This means that the characterisation factors for CH_4 (fossil) is corrected from 30 to 30.5 kg CO_2-eq./kg CH_4, and for CH_4 (biogenic) it is corrected from 28 to 27.75 kg CO_2-eq./kg CH_4.

By default, the results for global warming do not include biogenic CO_2 uptake and emissions, except for CO_2 emissions that are related to land use changes.

CO_2 caused by land use changes (see section 2.9 and 3.2) are modelled as accelerated CO_2 emissions. The global warming effect of this is calculated by use of time-dependant GWP100. This is described in Schmidt et al. (2015).

2.11 Uncertainties and Data quality

It is obvious that a database as The Big Climate Database, which includes hundreds of millions of data points is associated with uncertainties. The model cannot produce more precise results than the preciseness of data inputs.

The database has been constructed and documented in a way so that the user can access all flow data points behind each result. This feature is available in the web-version of the database at: http://denstoreklimadatabase.dk/

The objective is that by transparently displaying all data behind, errors and wrong data inputs can easily be identified by users and issues can easily be fixed and a new version of the database can be published.

The crop and animal production modules have been produced mainly based on data obtained from FAOSTAT (2020) combined with emission models in IPCC (2006) with supplements (IPCC 2014). Obviously, global statistical data on crop yields and animal production are associated with uncertainties. Uncertainties in these data and models migrate into the results. Further, the detailed recipes and inventories for specific food processing industries may be associated with varying representativeness and uncertainties in data.

It has not been possible to quantify the uncertainties within the scope of the current version of The Big Climate Database.

3 Life cycle inventory: Background system

3.1 LCI background system: EXIOBASE

Background data are used to include upstream emissions and resources related to the in- and outflows mapped in the foreground system, e.g. emissions associated with the production of electricity and fertiliser. The method used is a consequential LCA model for which all data are obtained from the EXIOBASE v3.3.16b2 database.

EXIOBASE is a global hybrid multi-regional environmentally extended input output (IO) database. The EXIOBASE v3 database (http://www.exiobase.eu/) is the product of four large EU funded projects under the 6th and 7th framework programmes: FORWAST (http://forwast.brgm.fr/), EXIOPOL (http://www.feem-project.net/exiopol/), CREEA (http://www.creea.eu/) and DESIRE (http://fp7desire.eu/). EXIOBASE can be used for national level footprints (http://www.exiobase.eu/index.php/9-blog/27-creea-booklet) as well as background LCI database for detailed product LCAs and corporate footprints. The advantage of using an IO-database instead of a process database, such as ecoinvent, is that it operates with a cut-off criterion at 0% and that it has a much more complete geographical scope than any process database. Further, the hybrid version of EXIOBASE, which is used in the current study, has been constructed from supply-use tables using the by-product technology assumption, which is identical to substitution in LCA (Suh et al. 2010).

The newest hybrid version of EXIOBASE (version 3.3.16b2) has the following characteristics:

- Product flows in hybrid units: EUR, kg, MJ.
- 43 countries, 5 Rest-of-the-world regions
- Base year: 2011
- 164 activities/products (this is equivalent to LCA processes in a conventional LCA database)
- 34 emissions, 22 resources, land use, water
- Employment per three skill levels

Figure 3.1: Geographical resolution of EXIOBASE v3.

Besides, the characteristics listed above, the 'b2' version of the hybrid version of EXIOBASE is special in the sense that a model for indirect land use changes (iLUC) is integrated, electricity mixes represent long term marginal marginal supply mixes (build marginal), and investments are integrated into the core transaction matrix, which means that GHG emissions from a certain product also includes the emissions associated wioth the manufacture of the machines used to produce the product ass well as the construction of the buildings that house the manufacturing processes.

The used version of EXIOBASE is documented in two core papers: Stadler et al. (2018) and Merciai and Schmidt (2017a). In the sections below, different central components of the EXIOBASE are further elaborated.

3.2 Indirect land use changes (iLUC)

According to IPCC (2020), 11% of global GHG emissions were relate to land use changes in 2007-2016. A major challenge in modelling LUCs is to ascribe the effects to their drivers. We use a model for iLUC proposed by Schmidt et al. (2015). This model has been used for a large number of LCA studies and carbon footprints[3] and the model is rated as the best among a comparison of six major LUC models by De Rosa et al. (2016). The ranking considers completeness, impact assessment relevance, scientific robustness, and transparency. The current study uses version 4.3 of the iLUC model, which is integrated in the multi-regional hybrid input-output model Exiobase v3 (Merciai and Schmidt 2017a,b; Schmidt and De Rosa 2018). The applied iLUC model has been and is currently being developed through an initiative lead by 2.-0 LCA consultants: The 2.-0 iLUC club (http://lca-net.com/clubs/iluc/). The initiative is supported by more than 25 partners including large multinational companies, national research centres, NGOs and universities. The partners are located in 11 different countries in Europe, Asia, North America and Australia.

The iLUC model has several key characteristics that make it superior to many of the other models:

- It is applicable to all crops (also forest land, range land, built land etc.) in all regions in the world.
- It avoids arbitrary allocation/amortization of transformation impacts.
- It is based on modelling assumptions that follow cause-effect relationships consistent with the way any other links between LCA-processes are modelled.

According to Schmidt et al. (2015), the cause of land transformation is a change in the demand for land. The mechanism linking land use change to changes in demand for land is illustrated in **Figure 3.2**. The figure uses the example of adding a demand for land for rapeseed in Denmark of 1 ha*year. It appears from the figure that the land use effects can be divided into direct and indirect land use changes. This is further explained in the following.

[3] See list of examples of application areas at: https://lca-net.com/projects/show/indirect-land-use-change-model-iluc/

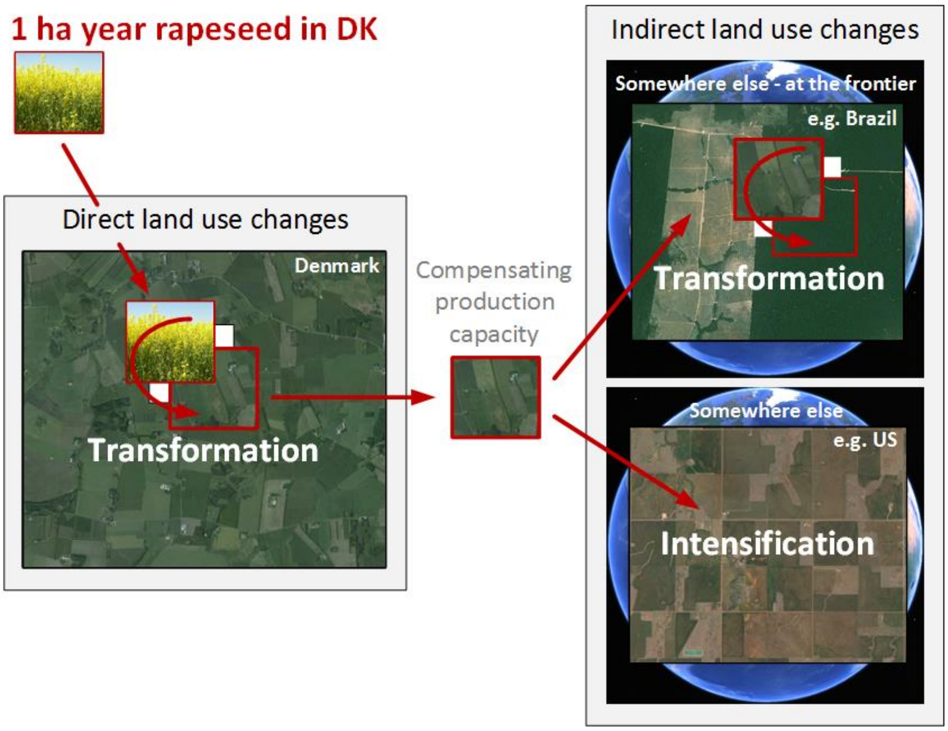

Figure 3.2. Illustration of the effects of adding a demand for land in Denmark of one hectare*year. The effects include indirect transformation of land and intensification to compensate for the production capacity in Denmark that is now no longer available due to being occupied by the new demand.

Direct land use changes (dLUC)

In the example in **Figure 3.2**, the direct land use change is the effect of changing from a reference situation to rapeseed. The reference situation is the current marginal use of the affected land, which will be arable land in most cases (Schmidt et al. 2015).

Obviously, any arable cropping will affect arable land, but also many other human activities are located on arable land, so that when demanding land for buildings, infrastructure, sites for resource extraction, etc., arable land is often affected. An example is the demand for land for POME treatment ponds. This will occupy land that would else have been used for oil palm. Another example is the use of land for a residential house in an urban area. This change in demand for land will put equivalent pressure on the boundaries of the urban area that will likely expand into the surrounding arable land. Even when a previously forested area is used for arable land, the marginally affected land is arable. This is because this piece of land is likely to be the next to be put into agricultural production anyway. So, if oil palm grower 'A' does not convert the land, then it is likely that another grower 'B' will make use of the specific land. This is the case in places where forests and agriculture is in competition for the same land.

Most often, the impacts of direct land use changes are small, because the carbon stock and biodiversity hosted on the land are similar for the specific use and for the reference. When the crops under study are associated with a carbon stock that is equal to the reference in that country, then the direct land use changes are not associated with any change in carbon stock. However, if the crops under study stores more carbon than the reference, then the crops under study contribute to an increase of stored carbon in crops in that country. This is the case of oil palm, which stores more carbon than reference, which will be the average of arable land in Indonesia and Malaysia.

Indirect land use changes (iLUC)

As illustrated in **Figure 3.2**, the indirect consequence of the direct land use change is the occupation of production capacity somewhere else to compensate for the production capacity now occupied by the additional demand. According to Schmidt et al. (2015), this compensation is partly expansion of arable land at the agricultural frontier, and partly intensification of land already in use. The use of land by the crop under study is what is considered as dLUC, while the supply of new land caused by the need for compensating the production capacity of the land required by the new demand is considered as iLUC. The link between the supply-side and the use-side of land is further elaborated in the next section.

Supply and use of land linked via the global market for land

The iLUC model described in Schmidt et al. (2015) assumes there is a global market for land. To be more precise, the market is not mainly concerned with the area of land but rather its production capacity. Hence, all countries that expand their arable land supplies land into this market as well as all countries that intensify their existing productive land supply arable land into the global market for arable land. This supply-side to the global market for land is illustrated in **Figure 3.3**.

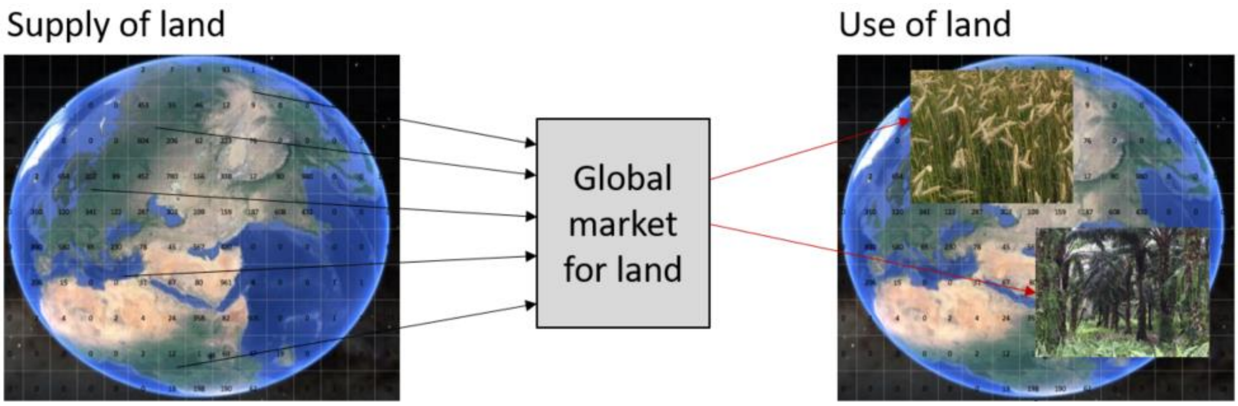

Figure 3.3. Illustration of the global supply and demand of land (Schmidt and De Rosa 2018).

The supply-side of land is modelled using the Exiobase model, and the approach and data are described in Schmidt and De Rosa (2018) and Merciai and Schmidt (2017b).

The supply of land in the applied iLUC model is modelled by using data in the multi-regional hybrid input-output model Exiobase (Merciai and Schmidt 2017a). The integration of the iLUC model in Exiobase is described in Merciai and Schmidt (2017b) and Schmidt and De Rosa (2018). The land market modules of the model contain data on time-series of land use data and agricultural production data for all countries. The Exiobase data allow identifying the land supplied by each country, by expansion of the cultivated area as well as by intensifying existing agricultural land and linking the production trends with the land use trends. In Exiobase, the complete global economy is divided in 48 countries and regions, and each of them is divided in 164 industrial sectors. The agricultural and land use module in Exiobase make use of FAOSTAT (2018), which provide time series on area and production per crop. To have comparative yields, all crops are converted to dry matter. These data allow modelling the global supply of land (**Figure 3.3**) to the global market for land, distinguishing between land expansion (land transformation) and land intensifications (increased production per unit of land). Analogously, the demand side is modelled for every country using land for crop cultivation, pasture, forestry and other purposes.

Adjustment for differences in potential productivity

To calculate how much land that needs to be compensated from occupying 1 ha*year in a specific country/region, its productivity must be adjusted for. Schmidt et al. (2015) use the potential net primary production (NPP_0) for this adjustment. Hence, the adjustment factor is calculated as the actual NPP_0 divided by the global average NPP_0 for arable land. When this adjustment is done, the unit is changed from ha*year to ha*year-equivalents, where 1 ha*year-equivalent refer to land with average global potential productivity.

The potential productivity of arable land in different countries is based on high resolution maps that allow to determine how much iLUC is induced by using land in different regions. For example, 1 ha arable land in Indonesia gives a potential productivity that is 1.9 times greater than in EU28, hence the induced iLUC emissions from 1 ha in Indonesia is 1.9 times higher than in EU28. The data used to determine national average potential productivity of arable land relative to global average arable land is a detailed overlay analysis in GIS, with the following data sources:

- 10 x 10 km grid of potential net primary production (NPP_0) (Haberl et al. 2007)
- 0.05 x 0.05 km grid of land cover data (Friedl et al. 2010)
- National borders

Different land markets

Schmidt et al. (2015) operate with different markets for land: 1) Arable land, 2) Intensive forest land, 3) Extensive forest land, and 4) Grassland. This delimits land types with different potential uses. The potential uses represent the reference for each land type, e.g. grassland in the dry Brazilian Cerrado, which is to a large extent used for cattle grazing, cannot be used for forestry or arable cropping because it is too dry for these purposes. Therefore, a change in the use of these grasslands will not have any indirect effects on the markets for forest land or arable land. Similarly, forest land in some countries may not be fit for arable cropping because the land is too cold, rocky or hilly for that purpose. Therefore, the use of this land will only affect the market for forest land. Sometimes land is used for less productive purposes (economically) than the land's potential use, e.g. when potential arable land in Indonesia and Malaysia is used for extensive forestry. In this case, using this land will still affect the market for arable land. (Schmidt and de Saxcé 2016)

The markets for land are defined in **Table 3.1**.

Table 3.1. Different markets for land (based on Schmidt et al. 2015)

Markets for land	Description
Market for arable land (fit for arable and other)	Fit for arable cropping (both annual and perennial crops), for intensive or extensive forestry, and pasture.
Market for forest land (fit for intensive/extensive forestry and grazing)	Fit for forestry and pasture, but unfit for arable cropping e.g. because the soil is too rocky or because the climate is too cold. Forest land may also be used for other uses, e.g. livestock grazing.
Market for grassland (fit for grazing)	Too dry or cold for forestry and arable cropping. Grassland is most often used for grazing.

Temporal aspects: Avoiding amortization of land transformation

A challenge when modelling land use changes is that transformation of land (in unit ha), e.g. from forest to soybean, is not proportional with soybean production (which is proportional with land occupation in unit ha*year). A common approach to overcome this is to amortize (allocate) impacts related to land transformation over a normatively defined historical period of time, e.g. 20 years. This approach is used in several LCA and carbon footprint guidelines, e.g. the PEF guideline, the GHG protocol, and PAS2050.

However, this approach does not reflect a cause-effect relationship, the amortization period is arbitrarily defined, and by allocating historical land use change impacts to current oil palm cultivation it implies a causality that goes backwards in time (current demand for soybean causes deforestation 20 years ago), which is obviously not possible in reality.

The applied iLUC model overcomes this problem by modelling land transformation as accelerated denaturalisation (Schmidt et al. 2015). This approach models the observed and current relationships only: that deforestation is taking place as long as the demand for land grows and as long as deforestation is not stopped. To grow the functional unit under study in an LCA, the indirect effect could be an additional demand for 1 ha*year. When this demand is added to the background demand causing the current deforestation, the effect is that in year 0, an additional hectare of deforestation is taking place, while after one year when the functional unit is produced, the cleared land can be handed over to the next crops, which can then be grown without deforestation. The handing over of the land after 1 year thus avoids 1 ha deforestation. The net effect of the additional demand for 1 ha*year is thus an acceleration of 1 ha deforestation by 1 year, i.e., the deforestation that would have taken place in year 1 is now taking place in year 0 because of the demand for the functional unit under study. When moving deforestation and associated CO_2 emissions in time, the impact on global warming can be calculated by using the time-dependant global warming potential. This is further described in Schmidt et al. (2015).

3.3 Electricity

LCI data for the production of electricity is obtained from the Exiobase v3.3.16b2 database. The Exiobase data for electricity are described in Merciai and Schmidt (2017b). The determination of the electricity mixes follows the same approach as described in Muñoz et al. (2015), which has recently also been applied in the consequential version of ecoinvent v3.4.

Table 3.2. Examples of marginal electricity mixes in some selected countries involved in the product system. Exiobase region abbreviations: AR = Argentina, BR = Brazil, DK = Denmark, ID = Indonesia, MY = Malaysia, RU = Russia, US = Unites States of America, UA = Ukraine, WA = rest of Asia, WE = rest of Europe, WL = rest of Latin America.

Source	DK	ID	MY (represented by WA)	BR	US	RU	AR (represented by WL)	UA (Represented by WE)
Coal		44%				1%	75%	84%
Natural gas		35%	8%	59%	77%	48%	14%	
Nuclear			2%	5%	19%		3%	6%
Hydropower		6%	71%	9%		16%		
Wind power			2%	25%		0%	1%	0%
Oil		9%	2%		4%	32%		
Biomass		0%	15%	2%		1%	7%	1%
Solar photovoltaic				1%				
Geothermal		6%		1%		2%		9%
Sum		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

3.4 Fuels and combustion emissions

Emission factors, densities and calorific values are available for all relevant fuels in the product system, as shown in **Table 3.3.**

Table 3.3: Emission factors, densities and calorific values for relevant fuels in the product system (Nielsen et al. 2016; Nielsen et al. 2018; Schmidt and De Saxcé 2016).

Parameter	Unit	Fuel oil	Diesel	Natural gas	Coal	Biomass
Properties						
Density	kg/m³			0.8		
Calorific value	GJ/t	42.7	43.1	49.54	24.33	19
Emission factors						
Carbon dioxide	kg/GJ	74	74	56.95	94.17	
Methane	kg/GJ	0.003	0.003	0.0017	0.0009	0.015
NMVOC	kg/GJ	0.0008	0.0008	0.002	0.0012	0.01
Dinitrogen monoxide	kg/GJ	0.0006	0.0006	0.001	0.0014	0.004
Carbon monoxide	kg/GJ	0.015	0.015	0.015	0.01	0.24

Nitrogen oxides	kg/GJ	0.15	0.15	0.055	0.03	0.09
Sulfur dioxide	kg/GJ	0.023	0.023	0.0003	0.009	0.025
Particulates, <2.5 um	kg/GJ	3.50E-07	3.33E-07	6.98E-08	3.56E-07	3.38E-05

LCI data for the production of fuels are obtained from the EXIOBASE database. Fuels are sourced from the national product market in the country where the fuel using activity is located.

3.5 Transport

Transport of crops, animals and other raw materials to food processing as well as to retail is modelled based on the distances between the supplying country and retail in Denmark. Table 3.4 provides an overview of the transport distances with lorry and ship. A default transport distance in Denmark at 200 km has been assumed.

Table 3.4: Applied transport distances. Rod distances are estimated based on google maps (https://www.google.com/maps) and sea distances on Sea Distance Calculator №1 (http://www.shiptraffic.net/2001/05/sea-distances-calculator.html)

Origin	Lorry distance, km intra DK	to DK (Aarhus)	to foreign port	Sea distance, km	origin port	destination port
AT	200	1,350				
AU	200		1,500	25,302	Port of Sydney	Port of Rotterdam
BE	200	956				
BG	200	2,549				
BR	200		1,500	12,499	Port of Santos	Port of Rotterdam
CA	200		1,500	6,280	Port of Montreal	Port of Rotterdam
CH	200	1,275				
CN	200		1,500	22,222	Port of Shanghai	Port of Rotterdam
CY	200		100	6,958	Famagusta Port	Port of Rotterdam
CZ	200	1,065				
DE	200	610				
DK	200					
EE	200	300	600	396	Port of Klaipeda, Lithuania	Port of Karlshamn
ES	200	2,498				
FI	200		300	1,383	Port of Helsinki	Port of Aarhus
FR	200	1,606				
GB	200	1,661				
GR	200		400	6,288	Port of Piraeus	Port of Rotterdam
HR	200	1,731				
HU	200	1,551				
ID	200		400	17,896	Port of Tanjung Priok	Port of Rotterdam
IE	200	1,732	200	107	Dublin Port	Port of Holyhead
IN	200		1,500	13,284	Mumbai Port	Port of Rotterdam
IT	200	2,078				
JP	200		400	23,848	Port of Nagoya	Port of Rotterdam
KR	200		400	23,178	Port of Busan	Port of Rotterdam
LT	200	300	600	396	Port of Klaipeda, Lithuania	
LU	200	985				
LV	200	300	600	396	Port of Klaipeda, Lithuania	Port of Karlshamn
MT	200		100	5,173	Port of Valletta, Malta	Port of Rotterdam
MX	200		1,000	16,179	Port of Manzanillo	Port of Rotterdam
NL	200	763				
NO	200		400	922	Port of Bergen	Port of Aarhus
PL	200	963				
PT	200	2,953				
RO	200	1,963				
RU	200		2,000	8,045	Novorossiysk Commercial Sea Port	Port of Rotterdam
SE	200		556	241	Port of Halmstad	Port of Aarhus
SI	200	953				
SK	200	1,339				
TR	200		500	6,769	Port of Mersin	Port of Rotterdam
TW	200		200	21,176	Port of Kaohsiung	Port of Rotterdam
US	200		1,500	7,256	Port of New York	Port of Rotterdam
WA	200		400	16,877	Port of Klang, Malaysia	Port of Rotterdam
WE	200		400	7,534	Port of Chernomorsk, Ukraine	Port of Rotterdam
WF	200		1,500	7,951	Port of Abidjan, Ivory Coast	Port of Rotterdam
WL	200		1,500	12,601	Port of Panama, Panama	Port of Rotterdam
WM	200		1,000	8,627	Jeddah Islamic Port, Saudi Arabia	Port of Rotterdam
ZA	200		500	15,107	Port of Durban	Port of Rotterdam

Transport by lorry is modelled using the EXIOBASE activity: 'Other land transport [country]'. The EXIOBASE transport activities are given with transport in monetary units and fuel inputs in mass unit. Hence, for the EXIOBASE transport activities the fuel use per transport service can be calculated as kg diesel/EUR transport. The corresponding proportion in units of kg diesel/tkm is identified in the ecoinvent database. By combining these two proportions, the reference flows of the EXIOBASE road transport activities can be converted to tkm.

3.6 Markets for feed energy and feed protein

Several foods are produced with by-products of animal feed. This is modelled using substitution in accordance with ISO 14040/44. In the following the marginal animal feed is identified and described.

Feed constitutes two main components: protein and energy. This section describes the marginal sources of feed protein and energy, which are substituted by the animal feed by-products. I.e. it is described which crops and downstream processing are influenced by a change in demand for marginal feed protein and energy, and how this is modelled.

Inputs to feed markets: The consequential model reflects the consequences of a change in demand for feed by identifying the marginal suppliers, i.e. the most likely crop/feed type to be affected by a change in demand for protein and energy respectively. The applied modelling of feed divided into proteins and energy feed reflects the way that farmers design the feed mix to have a balanced protein/feed ratio. Small speciality feed components, such as vitamins and minerals, are regulated by adding these to the ration, separately. Since the quantities of these are small, they are not accounted for in the current study. The modelling approach is similar to the one used in the consequential version of ecoinvent 3, and it is documented in e.g. Schmidt and Weidema (2008), Schmidt et al. (2009), Schmidt (2010) and Schmidt (2015). Assuming that the markets for protein and feed energy are global and independent (Schmidt and Weidema 2008; Schmidt 2015b), cereal grain is identified as the marginal feed type for feed energy and soybean meal as the marginal feed type for protein (Schmidt 2015b).

Because protein feed such as soybean meal also contains energy, the feed protein production has a by-product of energy that affects the market for feed energy. Vice-versa, feed energy crops such as maize grains contain protein, thus the feed energy production generates a by-product of protein that affects the protein market. These links create a loop in the life cycle inventory modelling: demand for protein partially displaces energy, which in turn displaces some protein etc. This algebraic problem is solved using standard LCA calculations, where the by-products are represented as negative inputs to LCA activities. For more details, see (Schmidt et al. 2009).

The crop types and their country of origin for the marginal feed protein and energy types are identified based on production data from FAOSTAT (2018). According to FAOSTAT (2018), the three most widely used grain crops globally are maize, wheat and barley, which are all grown in several countries. In order to identify the countries that primarily respond to increased demand in the global market, we calculate the increase in production in the period 2012-2016 by linear regression for all countries and rank the countries according to the highest increase rate (slope). Consistent with the methodology, to identify marginal suppliers in LCA (Weidema et al. 2009, Weidema 2003), the marginal producers/countries for each crop are the most competitive suppliers. Here we use the increase rate of crop production as an indicator for the competitiveness for country.

Table 3.5 shows that maize grown in the United States is the crop with the largest annual production increase, followed by Russian wheat, Argentinian maize and Ukrainian wheat. Together these four grain crops account for more than 63% (=39 + 14 + 6.9 + 4.2) of the annual production increase in 2012-2016, as presented in the column 'Share of change'. The amounts of grain crops identified in FAOSTAT (2018) have been converted to gross energy by using **Equation 3.1**:

Equation 3.1

$$GE\ [MJ] = Fat\ [kg] \times 36.6 [MJ/kg] + Crude\ protein\ [kg] \times 24.1\ [MJ/kg] + Carbohydrates\ [kg] \times 18.5\ [MJ/kg]$$

The fat, crude protein and carbohydrate contents of crops are obtained from Møller et al. (2005).

The percentage distribution presented in the column on the right is used to calculate the average marginal grain crop.

The countries with the highest increase rate of soybean cultivation are US and Brazil. Soybeans in the US and Brazil are the crops that primarily respond to changes in demand for protein in the global market. The life cycle inventory in the model is based on 52% soybeans from USA and 48% soybeans from Brazil.

Table 3.5. Crops responding to changes in demand for feed energy (grain crops) and feed protein (protein crops).

Crop, country	Unit	Annual production increase (2012-2016)	Share of change	Applied supply mix
Grain crops				
Maize, USA	PJ gross energy	373	39%	61%
Wheat, Russia	PJ gross energy	132	14%	22%
Maize, Argentina	PJ gross energy	67	7%	11%
Wheat, Ukraine	PJ gross energy	41	4%	7%
Other, increase	PJ gross energy	577	60%	
Other, decrease	PJ gross energy	-228	-24%	
Total			**100%**	**100%**
Soybean				
Soybean, USA	Million t crude protein	3.14	37%	52%
Soybean, Brazil	Million t crude protein	2.85	33%	48%
Other, increase	Million t crude protein	2.97	35%	
Other, decrease	Million t crude protein	-0.38	-4%	
Total			**100%**	**100%**

The LCI data for the global market for feed protein and feed energy are shown in **Table 3.6**.

Table 3.6. Life cycle inventories for feed protein and feed energy. The LCI data for the crops mentioned in this table are described in **Table 3.7**.

Flows	Unit	Feed protein {GLO} Transforming soybean meal to feed protein	Feed energy {GLO} Transforming wheat and maize to feed energy
Output: reference flow			
Feed protein, crude protein	kg	0.468	
Feed energy, gross energy	MJ		1.00
Output: by-products			
Feed protein, crude protein	kg		0.0052
Feed energy, gross energy	MJ	18.0	
Inputs			
Maize {US}	kg		0.0353
Wheat {RU}	kg		0.0132
Maize {AR}	kg		0.0064
Wheat {UA}	kg		0.0041
Soybean meal {US}	kg	0.524	
Soybean meal {BR}	kg	0.476	

LCI data for crops: For each of the six crops in **Table 3.6** (soybean meal is obtained from soybean) life cycle inventory data are established. This includes determination of inputs (e.g. fertiliser, diesel, land, irrigation), outputs (crops and emissions). The input of land is linked with the indirect land use change model, which is integrated in the EXIOBASE database The LCI data for the six crops is presented in **Table 3.7**. The input of land in **Table 3.7** is referred to as market for arable land.

The amount of fertiliser used per hectare for each crop in the countries mentioned in **Table 3.6** is calculated by a top-down approach, by distributing the total fertiliser consumption in the relevant countries for 2015, on the agricultural area (IFA 2018). The distribution is crop specific, thus based on crop-specific harvested areas from FAOSTAT (2018) for the individual countries. Different crops require different amounts of fertiliser. Therefore, for each of the relevant countries, a crop-specific distribution key, based on data from IFA (2002), is used. Data on diesel consumption is based on Cederberg et al. (2009) and data on irrigation is drawn from the ecoinvent database (2017). Yields for 2016 are calculated by regression of yield data for 2012-2016 from FAOSTAT (2018). Emissions are calculated according to IPCC (2006) tier 1, which takes account of crop-specific yields, fertiliser inputs and crop residues, from which a detailed N-balance is established.

Table 3.7. Life cycle inventories for crops involved in the inputs to the marginal global markets for feed protein and feed energy in **Table 3.6**. All data are shown for 1 ha*year.

Flows	Unit	Maize {US} Maize cultivation	Wheat {RU} Wheat cultivation	Maize {AR} Maize cultivation	Wheat {UA} Wheat cultivation	Soybean {US} Soybean cultivation	Soybean {BR} Soybean cultivation
Reference flow							
Output: Crop	kg	11,406	2,710	7,610	4,317	3,494	3,000
Inputs: Energy							
Diesel	MJ	2,898	3,306	2,898	3,306	1,709	1,709
Lubricants and hydraulic oil	MJ	1.10	1.10	1.10	1.10	1.10	1.10
Inputs: Nutrients and chemicals							
Urea	Kg N	85.3	1.69	32.3	18.8	17.1	8.13
Ammonium nitrate	kg N	107	32.3	0	39.0	21.3	2.02
Calcium amm. nitrate	kg N	0	0	1.13	3.98	0	0.36
Ammonium sulphate	kg N	8.95	3.35	1.62	0.67	1.79	1.73
Phosphate rock	kg P_2O_5	0	13.6	0	13.5	0	1.91
Phosphate fertiliser	kg P_2O_5	49.8	0	27.3	0	42.7	59.3
Potassium chloride	kg K_2O	51.2	6.21	0.24	13.8	54.0	68.0
Potassium sulfate	kg K_2O	2.35	1.37	0	0	2.48	0.14
Input: Irrigation							
Irrigation (US)	m^3	2,792					
Irrigation (RU)	m^3		935				
Irrigation (AR)	m^3			1,181			
Irrigation (UA)	m^3				1,490		
Input: Transport							
Road transport {US}	tkm	0.735				0.306	
Road transport {RU}	tkm		0.121				
Road transport {AR}	tkm			0.139			
Road transport {UA}	tkm				0.195		
Road transport {BR}	tkm						0.295
Input: land, link to iLUC model							
Market for arable land	ha-eq.	1.02	0.93	1.32	0.98	1.02	1.33
Input: Capital goods and services							
Maize cultivation capital goods and services {US}	ha a	1					
Wheat cultivation capital goods and services {RU}	ha a		1				
Maize cultivation capital goods and services {AR}	ha a			1			
Wheat cultivation capital goods and services {UA}	ha a				1		
Soybean cultivation capital goods and services {US}	ha a					1	
Soybean cultivation capital goods and services {BR}	ha a						1
Emissions							
Ammonia	kg	23.8	4.40	4.08	7.36	4.72	1.39
Carbon dioxide	kg	138	2.72	52.0	30.3	27.5	13.1
Dinitrogen monoxide	kg	5.76	1.41	1.81	2.25	1.62	0.96
Nitrogen oxides	kg	1.47	0.36	0.47	0.58	0.42	0.25
Nitrate	kg	376	93	121	149	108	65.2

LCI data for soybean meal: Soybean meal is co-produced with soybean oil in the soybean mill. An increase in demand of soy protein results in an increased availability of soybean oil in the global market, which affects the production of the marginal supplier of oil, i.e. palm oil (Schmidt and Weidema 2008; Schmidt 2014; Schmidt 2015a). This means that the palm oil system is also affected by changes in the demand for protein. The affected palm oil is the industry average of RBD palm oil. LCI data for this are presented in Schmidt and De Rosa (2019). Similarly, because grain crops contain proteins, a change in demand for feed energy causes a change in availability of protein as a by-product, affecting the production of soymeal and subsequently palm oil. The correlation between the product systems for feed protein, feed energy and vegetable oil are described in detail in Dalgaard et al. (2008) and Schmidt and Weidema (2008).

LCI data for soybean meal production and refining of soybean oil are presented in **Table 3.8.** The table shows that the soybean oil mills produce soybean meal (reference flow) and crude soybean oil as a material for treatment. It is a material for treatment because it needs refining before it is substitutable on the market for vegetable oil and thereby become a by-product that will substitute alternative production. The refinery step is needed to ensure substitutability because crude oils have different contents of free fatty acids, e.g. 1 kg CPO (containing 5% free fatty acids) is not substitutable with 1 kg crude rapeseed oil or soybean oil. When the crude soybean oil is treated in the refinery, the by-product outputs substitute refined palm oil and PFAD.

Table 3.8. Life cycle inventories for the soybean meal involved in the inputs to the marginal global market for feed protein shown in **Table 3.6**.

Flows	Unit	Soybean meal {US} Soybean oil mill	Soybean meal {BR} Soybean oil mill	Crude soybean oil {US, BR} Treatment refinery	LCI data
Reference flow					
Output: Soybean meal	t	0.773	0.773		
Input: Crude soybean oil {US, BR}	t			1	Crude soybean oil {US, BR} Treatment of CSBO in soybean oil refinery
Input: Feedstock					
Soybean {US} Soybean cultivation	t	1.00			See **Table** 3.7
Soybean {BR} Soybean cultivation	t		1.00		
Output: Materials for treatment					
Crude soybean oil {US}	t	0.192			Crude soybean oil {US, BR} Treatment of CSBO in soybean oil refinery
Crude soybean oil {BR}	t		0.192		Crude soybean oil {US, BR} Treatment of CSBO in soybean oil refinery
Landfill of bleaching earth {ID}	kg			5.79	ID data for landfill has been used: Link to: Landfill of bleaching earth {ID}
Landfill of oil loss {ID}	kg			5.00	ID data for landfill has been used: Link to: Landfill of oil loss {ID}
Output: By-products that substitute alternative production					
Palm oil	t			0.983	Schmidt and De Rosa (2019)
Palm fatty acid distillate (PFAD)	t			0.012	
Input: Energy					
Natural gas	MJ	5.71-06	5.71E-06		Link to: Natural gas {ID&MY} Fuel and combustion
Fuel oil	MJ	3.40-06	3.40E-06	5.73E-06	Link to: Fuel oil {ID&MY} Fuel and combustion
Electricity {US}	kWh	12.2		14.5	Link to: Electricity {US} market
Electricity {BR}	kWh		12.2	14.5	Link to: Electricity {BR} market
Input: Water					
Water {US}	m^3	0.104		1.37E-02	Link to: Water {US}
Water {BR}	m^3		0.104	1.37E-02	Link to: Water {BR}
Input: Transport					
Road transport {US}	tkm	200		1.38	Link to: Road transport {BR} 16-32 t truck
Road transport {BR}	tkm		200	1.38	Link to: Road transport {BR} 16-32 t truck
Input: Material use					
Caustic Soda, as 100% conc.	kg			2.10	Link to: Caustic Soda, as 100% conc {ID&MY}
Phosphoric acid, as 100% conc.	kg			0.800	Link to: Phosphoric acid, as 100% conc {ID&MY}
Bleaching earth	kg			9.00	Link to: Bleaching earth {ID&MY}
Sulphuric acid, as 100%	kg			1.90	Link to: Sulphuric acid, as 100% conc {ID&MY}
Input: Capital goods and services					
Soybean mill capital goods and services {US}	t	1			Link to: Soybean mill capital goods and services {BR}
Soybean mill capital goods and services {BR}	t		1		Link to: Soybean mill capital goods and services {US}
Soybean oil refinery capital goods and services	t			1	This is already included with the input in the oil mill stage because the oils and fats sector in EXIOBASE includes both the milling and the refinery processes.

3.7 Rendering

Animal production and slaughterhouses produce animal wastes and by-products (so-called C1, C2 and C3 category materials). The treatment of these materials are processed into pet food/animal feed, fat, biodiesel, fertiliser and fuel substitute for coal. The life cycle inventory of the treatment of C1, C2 and C3 materials are obtained from a detailed life cycle assessment for DAKA, which is the dominant rendering company in Denmark (Schmidt and Trolle 2020).

3.8 Capital goods and services

When datasets for food manufacturing activities are constructed, data are typically only available for the food product, feedstock, process wastes/by-products and energy use. The remaining inputs of machinery, services, buildings etc. are added based on the inputs of these product categories in a representative average industry in the country, where the activity is located. E.g. the inputs of kg machines per kg wine in Spanish winemaking is based on the average input of machinery in the Spanish beverage industry. These data are obtained from EXIOBASE, see section 3.1.

4 Life cycle inventory: Crop cultivation

This section describes the data and methods for inventorying all crops in all countries in the world.

4.1 Data sources

Data on crop cultivation are obtained combining FAOSTAT with several data sources. FAOSTAT, which is the database provided by the Food and Agriculture Organization of United Nation, is the most accurate and consistent dataset on the agriculture and food production. It provides information on production and yields of several crops in all the countries of the world. This information has been integrated with data on the use of fertilizer so to determine a complete inventory of crops. Guidelines from the Intergovernmental Panel on Climate Change (IPCC) have been adopted for the calculation of GHGs emissions.

Table 4.1. List of data sources used for the Crop cultivation inventory.

Data source		Unit
FAOSTAT		
Crops	Production	tonnes
	Harvested Land	ha
	Yields	tonnes/ha
Animals	Stocks	Heads
National data (various sources)		
	Cropland organic soil	ha
	Grassland organic soil	ha
IFA		
Fertilizers	National Consumption	Thousands of tonnes
BACI		
Trade	Bilateral trade	tonnes

4.2 Consumption of fertilizers by crops

The mineral fertilisers applied to crops is integrated with volume of manure excreted indoor and spread on land. The manure excreted outdoor is instead assumed to be used in pasture land. The procedure to calculate the amount of manure available for each country is described in section 5.3.
Manure is then converted to fertilisers using the factors shown in **Table 4.2**.

Table 4.2. Coefficients used to convert the dry-matter excreted manure into N-fertilisers.

Animals	Kg N/tonne of DM manure	Source:	Conversion N-manure vs N-fertilisers (efficiency of N-manure)	Source:
Dairy cattle	62	(Poulsen & Kristensen, 1997)	0.5	(MFVM, 2001)
Other cattle	71	(Poulsen & Kristensen, 1997)	0.5	(MFVM, 2001)
Poultry	54	(Moore et al., 1998)	0.45	(MFVM, 2001)
Sheep/goats	27	(Poulsen & Kristensen, 1997)	0.45	(MFVM, 2001)
Swine	85	(Wesnæs M. et al., 2009)	0.55	(MFVM, 2001)

The requirement of nutrients for fodder crops are retrieved from Dalgaard et al. (2016, table 5.7). A procedure to include the peculiarities due to cultivation in greenhouses is also implemented.

A crop cultivated in greenhouses has higher yield and use more fertilisers per unit of land. However only some vegetables are grown in greenhouses. **Table 4.3** shows crops cultivated in greenhouses.

It is assumed that a country that has the highest yield in the world produces 100% of its crop in greenhouses. A country that has a yield lower than the world average is assumed not to use greenhouse. Lastly, a country with crop yield between the highest and the global yield is assumed to have a share of greenhouse cultivation equal to its yield divided by the highest.

With regard to use of fertilisers, it is assumed that the use of fertilisers is proportional to the yield. A fertiliser multiplicator is obtained dividing the highest yield by the average world yield, multiplied by an efficiency factor of 0.9. The results obtained with this approach are consistent with Torrellas et al. (2013).

Table 4.3. Crops cultivated in greenhouses. Elaboration of FAOSTAT data (FAO, 2020).

Crops	Country with highest yield	Highest yield (tonnes/ha)	Fertilizer multiplicator
Artichokes	WA	26.8	2.1
Beans, green	CY	38.1	2.3
Cucumbers and gherkins	NL	685.2	16.5
Eggplants (aubergines)	NL	486.5	15.3
Leeks, other alliaceous vegetables	KR	46.8	2.6
Lettuce and chicory	LV	41.0	1.7
Peas, green	PT	14.6	1.7
Spinach	CN	31.1	1.0
Strawberries	US	61.7	2.6

4.3 Field emissions from crop cultivation

The IPCC is a body of the United Nation that provides scientific information to be used by governments for developing climate change policies. IPCC also provides guidelines so that the inventory of the GHGs emissions can be calculated by governments in a consistent and scientific way (IPCC, 2006b). These guidelines have been used for the calculation of crop emissions of GHGs.

Data used to implement the IPCC guidelines consisted in the inputs of fertilisers to crops and the used of organic soil. Input of fertilisers have been described in section 4.2. It is assumed that crops only use mineral or synthetic fertilisers. With regard to the use of organic soil, the total 'Cropland organic soil' (IPCC, 2014) is distributed to crops using the harvested land. **Figure 4.1** shows the link between inputs and emissions in the crop cultivation inventory, while **Table 4.4** specifies the formulas adopted.

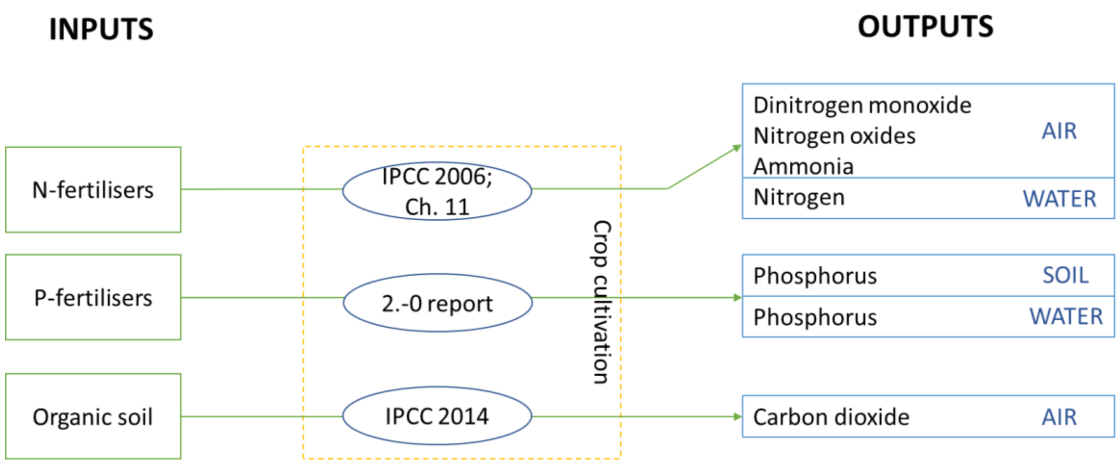

Figure 4.1. Links between inputs and outputs in the crop cultivation inventory and the methods adopted.

Table 4.4. Methods used for the calculation of crop emissions.

Type of emissions	Formula adopted
N20-direct	(IPCC, 2006b) - Eq. 11.1
N20-direct	(IPCC, 2006b)- Eq. 11.9/11.10
Ammonia + nitrogen dioxide	(IPCC, 2006b) Table 11.3
Nitrogen (water)	(IPCC, 2006b) Table 11.3
Phosphorus	(Dalgaard & Schmidt, 2012)
Carbon dioxide	(IPCC, 2014) Table 2.1

4.4 Link to iLUC model

The used iLUC model is described in section 3.2. The land use by a certain crop, i.e. the harvested land per year, is converted to land equivalents releative to global average productive land as described in section 3.2, subsection: 'Adjustment for differences in potential productivity'.

4.5 Other metadata

The inventory includes data on the dry matter coefficients (DMC) and the protein contents (PC) of crops. The DMC indicates the weight of 1 unit of crops once the moisture is removed. The PC indicates the protein included in one unit of crops. The wet weight indicates the weight of crops including the moisture. The data are presented in **Appendix 1: Dry matter and protein content of crops**.

4.6 The final inventory

Here it is shown an extract of the crop cultivation inventory for 3 main products used in The Big Climate Database.

Table 4.5. Extract of the crop cultivation inventory for three selected main products.

Crop inventory	Unit	Wheat - Denmark	Barley - Denmark	Soybeans - Brazil
Meta data				
Period	year	2016	2016	2016
DM coefficient	%	85%	85%	95%
Protein content (DM)	%	11.5%	10.8%	38.4%
Phosphorous content (DM)	%	0.37%	0.36%	0.67%
Total Harvested Area	ha	583,000	707,000	33,183,000
Share of organic soil	%	3%	3%	0%
Products and materials for treatment				
Reference flow	kg	7207	5587	2905
Input – land use	ha	1	1	1
Input - N-fertilizers	kg	177.75	92.43	16.90
Input - P2O5-fertilisers	kg	43.91	41.33	119.22
Input - K2O-fertilisers	kg	118.89	89.17	171.11
Output - Total residues	kg	7711	5978	6100
Output - Total residues used	kg	5549	4302	5229
Emissions				
Air - Carbon dioxide, fossil	kg	7.90	7.90	14.00
Air - Dinitrogen monoxide	kg	4.41	2.63	0.37
Air - Nitrogen oxides	kg	0.74	0.45	0.06
Air - Ammonia	kg	17.7	9.18	1.68
Water - Nitrogen, total	kg	237	123	24
Water - Phosphorus, total	kg	0.35	0.34	0.49
Soil - Phosphorus, total	kg	11.7	11.3	16.5

Data on the use of fertilizers have been linked to Exiobase v3.3.16. In particular, N-fertilisers have been linked to process 'N-fertiliser, market' and P2O5 and K2O fertilisers to 'P- and other fertilizer, market'.

5 Life cycle inventory: Animal production

This section describes the data and methods for inventorying all animal production systems in all countries in the world.

5.1 Data sources

The animal production inventory, so as the crop cultivation, uses the information provided by FAOSTAT and implement the IPCC guidelines (IPCC, 2006a). An important step is the breakdown of animal herd into meat and milk systems, which is necessary to determine the impact of the production of meat and dairy products. It is assumed that dairy system produces milk as main product and meat as by-product, while the meat system produces only meat.

The main data sources used for the animal inventory is listed in **Table 5.1**.

Table 5.1. Main data sources used for the animal production inventory.

Data source		Data	Unit
FAOSTAT			
Production	Live animals	Stocks	heads
	Livestock Primary	Producing Animals	heads
		Production Quantity	tonnes (carcass weight)
		Yield	tonnes/heads
Trade	Live animals	Import Quantity	heads
		Export Quantity	heads
BACI (CEPII, 2020)			
Trade	Live animals	Import Quantity	tonnes
		Export Quantity	tonnes

Data in **Table 5.2** are integrated with information on dressing percentages, which is the carcass weight divided by live animal weight, and lifespans of animals

Table 5.2. Additional default data on animal properties.

Animal:	Amount	Source:
Dressing percentage		
Cattle	60	(FAO, 1991)
Pork	70	(FAO, 1991)
Sheep	50	(FAO, 1991)
Goat	43	(UMD, 2009)
Camel	55.8	(Yousif & Babiker, 1989)
Lifetime (default values)		
Dairy cows	4.5	(Dalgaard & Schmidt, 2012)
Beef cow	10	(Dalgaard & Schmidt, 2012)
Sheep	7.5	Elaborated from (Claeys & Rofgers, 2003)
Goat	Assumed as sheep	

5.2 Breakdown of herds into meat and dairy systems

The objective of the breakdown of herds is to model the systems that produce milk and meat. Of course, because a fundamental condition is to preserve the mass balance, each system may also have co-productions. This means that dairy systems also produce meat for the quantity of slaughtered animals. On the other hand, meat system is assumed not to sell milk, the milk produced is only assumed to feed young animals.

In each system it is assumed that part of new born animals are kept for replacing end-of-life adult animals, while the residual part is only raised for meat production. End-of-life animals are directly dependent on the lifetime of animals. While the number of new-borns relies on the fertility rate of adult female animals. Because the number of replacing animals is equal to the end-of-life animals, it could be thought as a steady state system. Yet in the calculation the stock variation is taken into account. Given data shown in **Table 5.1**, the initial information available is depicted in **Figure 5.1**.

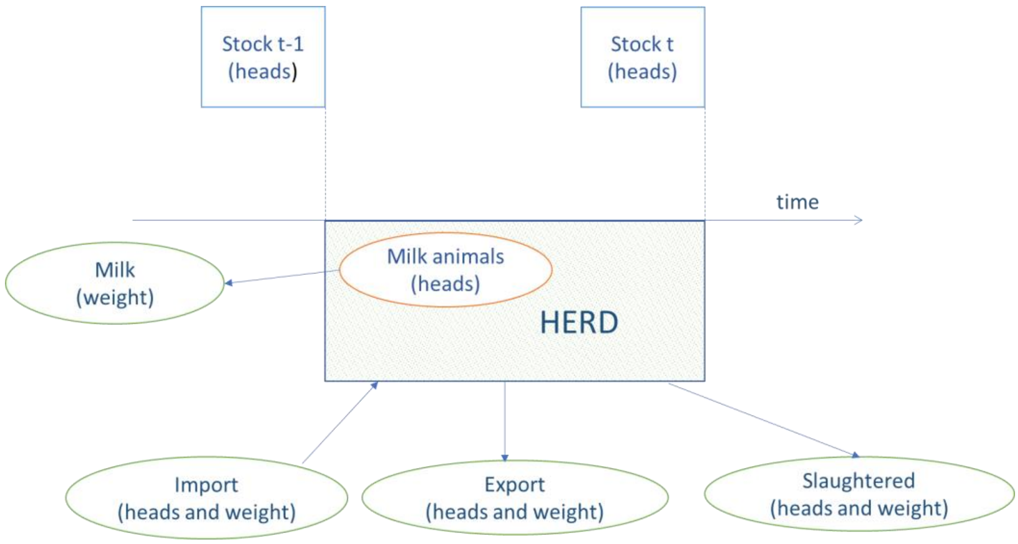

Figure 5.1. Scheme of the initial data availability.

Integrating data of **Figure 5.1** with additional information of **Table 5.2**, the final objective has been that of disaggregating the herd as shown in **Figure 5.2**.

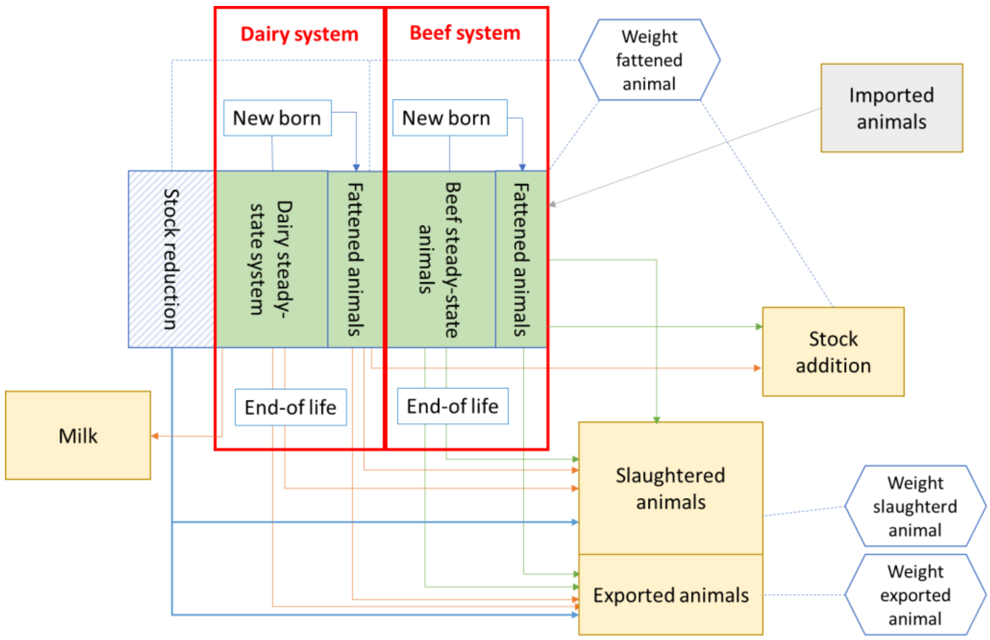

Figure 5.2. Breakdown of the cattle herd into diary and meat system.

The approach depicted in **Figure 5.2** is applied to cattle, buffalos, sheep and goats. A system expansion approach is implemented (see section 2.8). Therefore, the by-product of a system will replace a production elsewhere. For example, as shown in **Figure 5.2**, the meat produced by end-of-life cow will replace the production of meat in the beef system.

In some cases, it is not possible to divide the herds in dairy and meat because the productions are too integrated. This is the case mainly in goats and sheep. As consequence, there would be just one system producing both milk and meat. By default, it is assumed that whenever there is a milk production, an integrated system produces milk as main production.

5.3 Feed requirements and manure excreted

The amount of feed eaten by animal is obtained using the IPCC guidelines (IPCC, 2006a). Implementing these guidelines it is possible to determine the amount of dry matter intake of cattle, sheep and goats. Parameters to run the procedure described by IPCC (2006a) are taken from official statistics provided by countries to the National Inventory of United Nations Framework Convention on Climate Change (UNFCCC), as consequences of the agreements reached during United Nations Conference on Environment and Development (UNCED) (UNFCCC, 2017)[4]. Whenever the required information is not included in the national inventory, default values shown in the IPCC report are used. The output of this procedure is the dry matter intake of cattle, goats, sheep and camels. At the same time, it is also derived the total produced manure and, given the information of manure management, how much excreted indoor or outdoor.

Table 5.3. Procedure used to assess the amount of dry matter intake and produced manure by cattle, sheep and goats.

Type of emissions	Formula adopted
Type of emissions	
Estimate of annual population of herds	(IPCC, 2006a) - Eq. 10.1
Coefficient for Calculating Net Energy for Maintenance	(IPCC, 2006a) - Eq. 10.2
Net Energy for Maintenance	(IPCC, 2006a) - Eq. 10.3
Net Energy for Activity	(IPCC, 2006a) - Eq. 10.4/10.5
Net Energy for Growth (For Cattle and Buffalo) And (For Sheep)	(IPCC, 2006a) - Eq. 10.6/10.7
Net Energy for Lactation (For Beef Cattle, Dairy Cattle and Buffalo)	(IPCC, 2006a) - Eq. 10.8/10.9
Net Energy for Work (For Cattle and Buffalo)	(IPCC, 2006a) - Eq. 10.11
Net Energy to Produce Wool (For Sheep)	(IPCC, 2006a) - Eq. 10.12
Net Energy for Pregnancy (For Cattle/Buffalo and Sheep)	(IPCC, 2006a) - Eq. 10.13
Ratio of Net Energy Available in A Diet for Maintenance to Digestible Energy Consumed	(IPCC, 2006a) - Eq. 10.14
Ratio of Net Energy Available for Growth in A Diet to Digestible Energy Consumed	(IPCC, 2006a) - Eq. 10.15
Gross Energy for Cattle/Buffalo and Sheep	(IPCC, 2006a) - Eq. 10.16
Estimation of Dry Matter Intake for Growing and Finishing Cattle	(IPCC, 2006a) - Eq. 10.17
Estimation of Dry Matter Intake for Mature Beef Cattle	(IPCC, 2006a) - Eq. 10.18a
Estimation of Dry Matter Intake for Mature Dairy Cows	(IPCC, 2006a) - Eq. 10.18b
Ch4 Emission Factors for Enteric Fermentation from A Livestock Category	(IPCC, 2006a) - Eq. 10.21
Manure based on DMI intake	(IPCC, 2006a) - Eq. 10.24

The dry matter intake (DMI) for broilers, pigs and eggs production are directly taken from (Krausmann et al., 2008). The amount of manure excreted by chicken and pigs is derived coefficients on the animal metabolism provided by Schmidt (2010).

[4] Tables 3A and 3B in the National Inventory Submissions include all the necessary information for implementing the IPCC (2006a) procedure.

5.4 Animal feed

Animal feed may consist of several sources, such as primary crops, crop residues, by-products of food industries, fodder crops and grass. The only information that is ready to be used is the amount of crops used as animal feed that is included in the New Food Balances (NBS) provided by FAOSTAT (FAO, 2020). The latter indicates, for example, the volumes of cereals used as feed.

The amount of food by-products used as feed is not provided by FAOSTAT, yet it can be easily derived. NBS provides the amount of crop being processed and the output of food industry, therefore, operating a difference between the two quantities, it is possible to estimate the amount of food by-products used as feed. Of course, it has been assumed a certain loss of material derived from LCI inventories. **Figure 5.3** shows the applied procedure used to estimate the oilseed cake. The same approach is also used for other food by-products such as molasses.

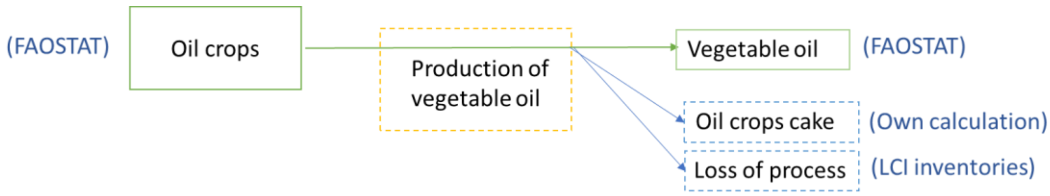

Figure 5.3. Procedure to estimate the food by-products used as feed.

The volume of food by-product so obtained, is then reconciled with trade statistics provided by FAOSTAT, which includes these quantities. In this way it has been possible to estimate the total amount of food by-products available as animal feed.

The amount of crop residues used as feed is derived multiplying the harvested crop by specific coefficients, which indicate how much of crop residues are used in different regions of the world as feed. These coefficients are retrieved from Wirsenius (2000).

At this point, on one hand, it is known the amount crops, food by-product and crop residues used as feed. These quantities are here referred as market feed (MF). On the other hand, it is known the amount of DMI of animals. The difference between the latter and the former gives the amount of feed that must be covered by residual fodder crops and grass. For simplicity this remaining part of animal feed is called feed gap (FG). The latter excludes all the fodder crops whose production is reported by FAOSTAT (FAO, 2020). For example, FAOSTAT reports only for some countries the production of green maize. In that case the feed gap includes all the other feasible fodder crops.

The procedure to calculate the feed gap is illustrated in **Figure 5.4**. Initially it is assumed that fodder crops and grass are not used for chicken and pigs. The main logic underlying the procedure is to assure that also cattle, goats and sheet have access to some market feed. It is assumed that al least 25% of their diet must include market feed[5]. Whenever this condition is not met, the market feed going to pigs is reduced. Once obtained the feed gap, it is necessary to associate to a land.

The land used as pasture is directly retrieved from FAOSTAT. However, the land used for residual fodder crops can be always derived from FAOSTAT subtracting the reported harvested crop area to the total crop land. Then the pasture of land is allocated to animals using the manure excreted outdoor as distribution

[5] The assumption of 25% is arbitrary. Unless there are country specific data on diet composition it is hard to define a standard diet that is valid worldwide. The reasoning behind the 25% is that of assuring a minimum of feed integration with cereals and other crops in the animal diet.

key (see section 5.3). It is assumed that a pasture land has a yield 4 time less than a field where fodder crops are grown[6]. Then the fodder gap that is not provided by grass is then provided by fodder crops. As results of the distribution of fodder cropland, also the land is finally allocated to animals.

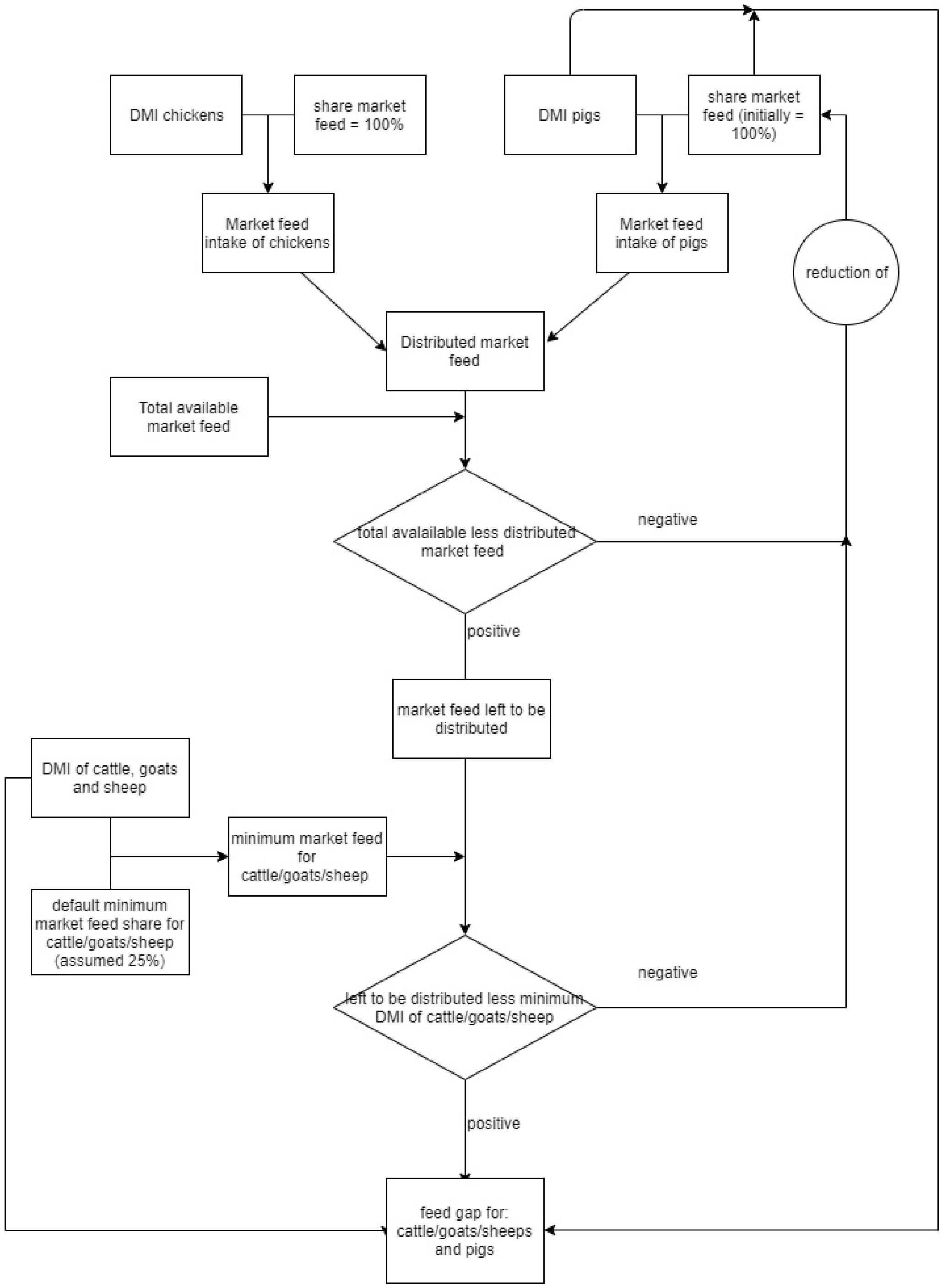

Figure 5.4. Diagram of the calculation of fodder gap.

[6] USDA indicates that common grass (Bermudagrass) has an yield of 3-5 tons/acre, while corn silage 12-18 tons per acre (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_014887.pdf). The derived yield per unit of fodder cropland is so derived: total feed gap/(fodder cropland + pasture land/4). Then yield of grass is the yield of fodder cropland divided by four.

5.5 The final inventory

Below in **Table 5.4** examples of animal inventory for four main animal systems are presented. Similar systems are created for all animal systems in all countries in the world.

Table 5.4. Extract of the final inventory for animals.

Crop inventory	Unit	Dairy cattle - Denmark	Broilers – Denmark	Pig – Denmark	Beef cattle – United States
Meta data					
Period	year	2016	2016	2016	2016
DM coefficient of reference flow	%	12%	43%	45%	32%
DM coefficient of by-product	%	32%			
Outputs					
Reference flow	kg	1	1	1	1
By-products					
Meat	kg	0.04			
Manure					
total manure excreted (DM)	kg	0.343	1.029	1.034	5.904
excreted indoor (DM)	kg	0.326	1.016	1.034	1.097
Inputs					
Barley	kg	0.024	0.042	0.057	0.006
Cottonseed	kg	0.000	0.000	0.000	0.018
Grapes	kg	0.000	0.000	0.000	0.003
Groundnuts (Shelled Eq)	kg	0.000	0.001	0.001	0.005
Maize	kg	0.129	0.701	0.948	3.257
Oats	kg	0.002	0.003	0.004	0.001
Rapeseed (incl. cakes)	kg	0.032	0.152	0.205	0.093
Rye	kg	0.004	0.006	0.008	0.000
Sorghum	kg	0.000	0.000	0.000	0.016
Soybeans (incl. cakes)	kg	0.110	0.598	0.809	0.926
Sunflower seed	kg	0.012	0.064	0.086	0.007
Sugar beet (molasses)	kg	0.036	0.193	0.262	0.230
Sugar cane (molasses)	kg	0.000	0.000	0.000	0.213
Triticale	kg	0.000	0.001	0.001	0.000
Wheat	kg	0.182	0.892	1.207	0.177
Other forages and Grass (DM)	kg	0.766	0.000	0.000	11.747
Other crops incl. residues	kg	0.000	0.001	0.002	0.031
Input - N-fertilizers	kg	0.018	0.000	0.000	0.110
Input - P2O5-fertilisers	kg	0.010	0.000	0.000	0.028
Input - K2O-fertilisers	kg	0.017	0.000	0.000	0.034
Pasture Land	m2a	0.19	0.14	0.00	146.30
Land for fodder crops	m2a	1.15	0	0	1.75
Emissions					
Air - Carbon dioxide, fossil	kg	0.035	0.009	0.000	0.244
Air - Dinitrogen monoxide	kg	0.001	0.000	0.001	0.017
Air - Methane, biogenic	kg	0.024	0.000	0.008	0.342
Air - Nitrogen oxides	kg	0.003	0.008	0.014	0.031

6 Crop and animal markets

Markets describes the producer mix for each crop and animal products. The main assumption used for markets it that a production that is constrained cannot be part of the market. A constrained production is for example the meat from dairy cow. In this case the farmer cannot decide to adjust the production as requested by consumers because the meat is produced by end-of-life cows or from animals that are not kept for replacing. Therefore, the beef market will be made only of farmer dedicated to a product market in Denmark, indicates the mix of countries that contribute to the supply of that commodity for the Danish consumer.

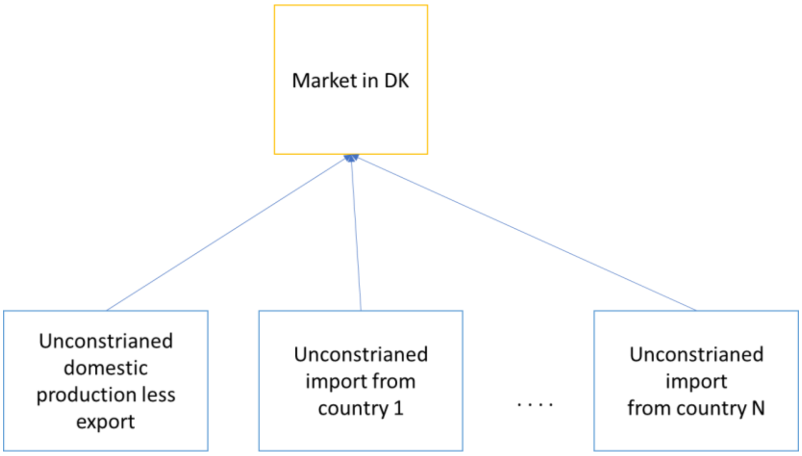

Figure 6.1. Illustration of the composition of markets.

Crop markets are then derived as the with data on crop production (FAO, 2020) and trade data from BACI (CEPII, 2020). Whenever there is a flaw in reported data, for example a product that is neither produced in Denmark nor imported, it is assumed a global market. Any country that exports unconstrained crops is assumed to belong to trade market. However, it can happen that the BACI does nort report minor product because the classification used is too aggregated. In that case a global market is made by all the countries that have an unconstrained production of that commodity. Market of animal products is made following the same logic.

Table 6.1. Extract of main Danish crop markets – year 2016.

Supplying country to DK market	Apples	Bananas	Potatoes	Tomatoes	Wheat
AT	0.8%	0.0%	0.0%	0.0%	0.0%
BE	0.8%	0.0%	0.0%	0.8%	0.0%
BG	0.0%	0.0%	0.0%	0.0%	0.0%
BR	1.2%	0.0%	0.0%	0.0%	0.0%
CA	0.0%	0.0%	0.0%	0.0%	0.0%
CY	0.0%	0.0%	0.0%	0.0%	0.0%
CZ	0.0%	0.0%	0.0%	0.0%	0.0%
DE	16.1%	0.0%	2.9%	8.2%	3.1%
DK	32.6%	0.0%	95.4%	24.8%	92.7%
EE	0.0%	0.0%	0.0%	0.0%	0.2%
ES	0.2%	0.9%	0.1%	45.0%	0.0%
FI	0.0%	0.0%	0.0%	0.0%	0.0%
FR	9.5%	0.0%	0.3%	9.5%	0.3%
GB	0.1%	0.0%	0.3%	0.0%	0.0%
GR	0.0%	0.0%	0.0%	0.0%	0.0%
HR	0.6%	0.0%	0.0%	0.0%	0.0%
HU	0.0%	0.0%	0.0%	0.0%	0.0%
IT	22.8%	0.0%	0.1%	8.8%	0.1%
LT	0.0%	0.0%	0.0%	0.0%	0.3%
LV	0.0%	0.0%	0.0%	0.0%	0.5%
NL	5.7%	0.0%	0.5%	0.0%	0.3%
NO	0.0%	0.0%	0.0%	0.0%	0.0%
PL	1.8%	0.0%	0.0%	1.3%	0.2%
PT	0.0%	0.0%	0.0%	0.0%	0.0%
SE	2.9%	0.0%	0.1%	1.0%	2.2%
SI	0.0%	0.0%	0.0%	0.0%	0.0%
TR	0.0%	0.0%	0.0%	0.4%	0.0%
WA	0.0%	0.1%	0.0%	0.0%	0.0%
WE	0.0%	0.0%	0.0%	0.0%	0.0%
WL	2.4%	99.0%	0.0%	0.0%	0.0%
WM	0.0%	0.0%	0.1%	0.0%	0.0%
ZA	2.5%	0.0%	0.0%	0.0%	0.0%
HU	0.0%	0.0%	0.0%	0.0%	0.0%
IT	22.8%	0.0%	0.1%	8.8%	0.1%
LT	0.0%	0.0%	0.0%	0.0%	0.3%
LV	0.0%	0.0%	0.0%	0.0%	0.5%
NL	5.7%	0.0%	0.5%	0.0%	0.3%
NO	0.0%	0.0%	0.0%	0.0%	0.0%
PL	1.8%	0.0%	0.0%	1.3%	0.2%
PT	0.0%	0.0%	0.0%	0.0%	0.0%
SE	2.9%	0.0%	0.1%	1.0%	2.2%
SI	0.0%	0.0%	0.0%	0.0%	0.0%
TR	0.0%	0.0%	0.0%	0.4%	0.0%
WA	0.0%	0.1%	0.0%	0.0%	0.0%

Table 6.2. Extract of main Danish animal product markets – year 2016.

Supplying country to DK market	Meat, cattle	Meat, chicken	Meat, pig	Milk, whole fresh cow
AT	0.3%	0.0%	0.0%	0.0%
AU	0.1%	0.0%	0.0%	0.0%
BE	0.3%	0.1%	0.0%	0.0%
BG	0.0%	0.0%	0.0%	0.0%
BR	0.2%	0.1%	0.0%	0.0%
CA	0.0%	0.0%	0.0%	0.0%
CH	0.0%	0.0%	0.0%	0.0%
CN	0.0%	0.0%	0.0%	0.0%
CY	0.0%	0.0%	0.0%	0.0%
CZ	0.0%	0.0%	0.0%	0.0%
DE	0.0%	2.1%	0.0%	0.0%
DK	0.4%	91.0%	99.2%	99.9%
EE	0.0%	0.0%	0.1%	0.0%
ES	0.4%	0.3%	0.0%	0.0%
FI	0.0%	0.0%	0.0%	0.0%
FR	0.3%	1.7%	0.0%	0.0%
GB	0.6%	1.7%	0.0%	0.0%
GR	0.0%	0.0%	0.0%	0.0%
Global market	92.6%	0.0%	0.0%	0.0%
HR	0.0%	0.0%	0.0%	0.0%
HU	0.0%	0.6%	0.0%	0.0%
ID	0.0%	0.0%	0.0%	0.0%
IE	1.2%	0.0%	0.0%	0.0%
IT	1.2%	0.1%	0.0%	0.0%
JP	0.0%	0.0%	0.0%	0.0%
LT	0.0%	0.0%	0.0%	0.0%
LV	0.0%	0.0%	0.0%	0.0%
MX	0.0%	0.0%	0.0%	0.0%
NL	2.0%	1.1%	0.1%	0.0%
NO	0.0%	0.0%	0.0%	0.0%
PL	0.0%	0.3%	0.1%	0.0%
PT	0.0%	0.0%	0.0%	0.0%
RO	0.0%	0.0%	0.0%	0.0%
SE	0.2%	1.0%	0.0%	0.0%
SI	0.0%	0.0%	0.0%	0.0%
SK	0.0%	0.0%	0.0%	0.0%
US	0.1%	0.0%	0.0%	0.0%
WA	0.0%	0.0%	0.0%	0.0%
WE	0.0%	0.0%	0.0%	0.0%
WL	0.2%	0.1%	0.0%	0.0%

7 Life cycle inventory: Fisheries

In the chapter, the modelling of fish production is described.

We model only fishes produced in aquaculture, because it is assumed that wild catch is a constrained resource, which cannot meet an increase in fish demand. On the contrary, aquaculture production of determined species has been increasing significantly. These are indicated as the marginal species in the tables below. The identification of the marginal species is based on the regression slope for 2008-2018 in FishStat (FAO 2020a).

Table 7.1. Freshwater fish aquaculture: key modelling data. Electricity data were obtained from Kim and Zhang (2018) thorough own elaboration based on the characteristics indicated in brackets (HT: high trophic value fish; LT: low trophic value fish).

Freshwater fish	Marginal	Modelled as:	Origin	Source of feed data (Table 7.4)	Electricity (kWh/kg)
Bream	Yes	Bream	China	As carp: FAO (2020c)	3.83 (LT)
Burbot	No	Tilapia	Indonesia	See tilapia	See tilapia
Charr	No	Tilapia	Indonesia	See tilapia	See tilapia
Perch	Yes	Perch	Bangladesh	Vongvichith et al. (2020)	6.85 (HT)
Pike	Yes	Pikeperch	Nigeria	See Perch	See Perch
Pikeperch	Yes	Pikeperch	Nigeria	See Perch	See Perch
Tilapia	Yes	Tilapia	Indonesia	FAO (2020e)	3.83 (LT)
Trout	Yes	Trout	Denmark	FAO (2020d)	6.85 (HT)
Whitefish	No	Tilapia	Indonesia	See tilapia	See tilapia

Table 7.2. Marine fish: Key modelling data. Electricity data were obtained from Kim and Zhang (2018) thorough own elaboration based on the characteristics indicated in brackets (CI: cold climate, Intensive aquaculture).

Marine fish	Marginal	Modelled as:	Origin	Source of feed data	Electricity (kWh/kg)
Cod	No	Salmon	Norway	See salmon	See salmon
Garfish	No	Salmon	Norway	See salmon	See salmon
Halibut	No	Salmon	Norway	See salmon	See salmon
Herring	No	Salmon	Norway	See salmon	See salmon
Mackerel	No	Salmon	Norway	See salmon	See salmon
Plaice	No	Salmon	Norway	See salmon	See salmon
Pollock	No	Salmon	Norway	See salmon	See salmon
Saithe (dark)	No	Salmon	Norway	See salmon	See salmon
Salmon	Yes	Salmon	Norway	FAO (2020b)	12.88 (CI)
Salmon (wild)	No	Salmon	Norway	See salmon	See salmon
Tuna	No	Salmon	Norway	See salmon	See salmon

Table 7.3. Mollusc and shell fish: Key modelling data. Electricity data were obtained from Kim and Zhang (2018) thorough own elaboration based on the characteristics indicated in brackets (WE: warm climate, extensive aquaculture).

Mollusc & shell fish	Marginal	Modelled as:	Origin	Source of feed data	Electricity (kWh/kg)
Mollusc					
Octopus	No	Mussel	Denmark	See mussel	-
Oyster	Yes	Oyster	USA	Naturally fed	0.015
Mussel	Yes	Mussel	Denmark	Naturally fed	-
Shell fish					
Crab	Yes	Crab	China	Unnikrishnan & Paulraj (2010)	3.21 (WE)
Crayfish	No	Shrimp	India	See shrimp	See shrimp
Lobster	No	Shrimp	India	See shrimp	See shrimp
Prawn (giant tiger)	Yes	Prawn (giant tiger)	Latin America	FAO (2020f)	3.21 (WE)
Shrimp	Yes	Shrimp	India	As prawn	3.21 (WE)

Table 7.4 shows the feed conversion rate (FCR) of the marginal species identified above and their respective feed composition.

Table 7.4. Feed Conversion Rate used (Fry JP et al. 2018) and composition of feed for the marginal fish species.

	Nile Tilapia	**Common carp**	**Trout**	**Atlantic Salmon (Marine)**	**Perch**	**Crabs**	**Giant tiger prawn**
FCR							
Feed conversion rate	1,7	1,7	1.3	1.3	1.4	As Prawn	1,7
Feed							
Source	FAO (2020e)	FAO (2020c)	FAO (2020d)	FAO (2020b)	Vongvichith et al. (2020)	Unnikrishnan & Paulraj (2010)	FAO (2020f)
Wheat, meal	15.0%	31.5%	19.2%	11.4%		20.3%	15.5%
Wheat, bran							6.3%
Wheat, gluten							3.8%
Wheat, middling							7.5%
Rice meal	10.0%	2.9%			30.5%		
Corn gluten meal	15.0%	8.8%	2.0%	5.6%	15.0%		
Barley meal		2.9%					
Rye meal		5.8%					
Vegetable oil	4.0%	0.2%	11.2%				
Soybean meal	20.0%	10.0%	5.4%	7.8%	22.1%	9.4%	17.3%
Soybean oil					3.1%		0.8%
Soy lecithin						1.0%	0.4%
Peas		5.8%					
Carrots		0.6%					
Cassava powder					4.2%		
Groundnut meal	10.0%						
Lupine		11.3%					
Lupine kernel meal							12.2%
Brewer's yeast				1.6%			
Vitamins	2.0%		1.5%	1.0%	2.1%	1.5%	
Minerals	4.0%	0.2%	0.5%	1.0%		5.0%	
Fish meal	15.0%	11.6%	49.2%	40.3%	23.0%	34.5%	18.1%
Fish oil				17.9%			1.8%
Fish soluble concentrate				1.0%			0.8%
Mussel meal						12.6%	
Squid oil						3.6%	0.8%
Squid meal						1.9%	5.5%
Shrimp meal						4.4%	6.1%
Shrimp head meal							3.1%
Poultry offal	5.0%	2.1%	4.6%	7.6%			
Blood meal		5.0%	2.4%	1.0%			
Feather meal			3.0%	3.8%			
Chemicals n.e.c.		0.2%				5.3%	
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

8 Life cycle inventory: Food processing industries

In this chapter the modelling of food processing industries are documented.

8.1 Slaughterhouse

The inventory for animal slaughtering has been built accounting for two steps:

- Slaughtering the live animal to obtain the carcass.
- Processing the carcass to obtain different cuts.

These two steps are described below for beef, pork and chicken, while for the other meats only the first step applies. The first step consists of a basic mass balance, while the second step takes into account that meat cuts are co-determining products (Schmidt 2010). A change in demand for one of the co-products will adjust so that they have the same market trend, thus affecting the production volume of the multiple output process in proportion to its share in the gross margin of the co-product. This is equivalent to the result of an economic allocation.

Beef

The mass balance for beef slaughtering is obtained from European Commission (2017), distributing the live animal weight into carcass, bones, fat, etc., as shown in Table 8.1. The distribution of the carcass weight into individual cuts is obtained from University of Tennessee Institute of Agriculture (Holland et al. 2014), except for the tenderloin, which is not reported in this source. This cut is assumed to represent the equivalent weight of 1/3 of that for the porterhouse steak. This additional weight is balanced by subtracting an equivalent weight from the sirloin steak. Use of water, electricity and natural gas is obtained from Blonk (2015). Production of wastewater is assumed equal to the volume of water used.

Table 8.1. Mass balance for beef slaughtering.

Flow	Tonne
Inputs	
Live animal	1
Outputs	
Meat and edible offal (carcass)	0.490
Round	0.080
Tenderloin	0.007
T-bone steak	0.011
Ground beef	0.075
Shank	0.022
Chuck	0.117
Standing rib roast	0.028
Rib steak	0.014
Short ribs	0.005
Braising beef	0.003
Porterhouse steak	0.021
Club steak	0.006
Sirloin steak	0.040
Brisket	0.011
Short plate	0.047
Flank	0.004
Bones	0.080
Fat	0.070
Category 3 slaughter by-products	0.070
Hides and skins	0.070
Category 1 and 2 material and waste	0.220

The processing of the beef carcass into meat cuts is not considered to involve any additional consumption of energy or any other material inputs, but results in different environmental burdens for the different cuts according to their prices, as described in Schmidt (2010). The prices used for the different cuts, expressed as USD/lb is obtained from Bringhurst (2020), as shown in Table 8.2. These prices are applied in the model in the same fashion as in a revenue allocation model, with the cheaper cuts receiving a higher share of live animal weight, energy use, waste production, etc., than the more expensive ones.

Table 8.2. Prices for beef cuts.

Beef cut	Price (USD/lb)
Round	6.89
Tenderloin	23.19
T-bone steak	12.29
Ground beef	4.09
Shank	5.99
Chuck	5.59
Standing rib roast	10.89
Rib steak	15.1
Short ribs	6.69
Braising beef	6.69
Porterhouse steak	13.59
Club steak	14.19
Sirloin steak	9.39
Brisket	11.49
Short plate	6.69
Flank	9.69

Pork

The mass balance for pig slaughtering is obtained from European Commission (2017), distributing the live animal weight into carcass, bones, fat, etc., as shown in Table 8.3. The distribution of the carcass weight into individual cuts is obtained from the National Pork Board (2020). In addition to cuts, the mass balance also includes liver as a co-determining product. The weight of the liver is estimated from Loeffel and Koch (1970). Use of water, electricity and natural gas is obtained from Blonk (2015). Production of wastewater is assumed equal to the volume of water used.

Table 8.3. Mass balance for pig slaughtering.

Flow	Tonne
Inputs	
Live animal	1
Outputs	
Meat and edible offal (carcass)	0.670
Ham	0.147
Minced meat	0.119
Backribs	0.017
Boneless loin	0.076
Sirloin roast	0.029
Tenderloin	0.009
Bacon	0.073
Spare ribs	0.037
Blade steaks	0.028
Blade roast	0.050
Boneless picnic meat	0.074
Liver	0.010
Bones	0.110
Fat	0.030
Category 3 slaughter by-products	0.190

The processing of the slaughtered pig into meat cuts is not considered to involve any additional consumption of energy or any other material inputs, but results in different environmental burdens for the different cuts according to their prices, as described in Schmidt (2010). The prices used for the different cuts, expressed as USD/lb is obtained from Riverdog Farm (2020), as shown in Table 8.4. These prices are applied in the model in the same fashion as in a revenue allocation model, with the cheaper cuts receiving a higher share of live animal weight, energy use, waste production, etc., than the more expensive ones.

Table 8.4. Prices for pork cuts.

Pork cut	Price (USD/lb)
Ham	10
Minced meat	8
Backribs	10
Boneless loin	12
Sirloin roast	10
Tenderloin	16
Bacon	14
Spare ribs	10
Blade steaks	10
Blade roast	10
Boneless picnic meat	8
Liver	6

Chicken

The mass balance for chicken slaughtering is obtained from European Commission (2017), distributing the live animal weight into carcass and by-products (bones, blood and meat meal) as shown in Table 8.5. The distribution of the carcass weight into individual cuts is obtained from the Australian Chicken Meat Federation (2020). Use of water, electricity and natural gas is obtained from Blonk (2015). Production of wastewater is assumed equal to the volume of water used.

Table 8.5. Mass balance for chicken slaughtering.

Flow	Tonne
Inputs	
Live animal	1
Outputs	
Meat (carcass)	0.728
Wings	0.080
Breast	0.298
Drumstick	0.124
Thigh	0.226
Bones, blood and meat meal	0.272

The processing of the slaughtered chicken into meat cuts is not considered to involve any additional consumption of energy or any other material inputs, but results in different environmental burdens for the different cuts according to their prices, as described in Schmidt (2010). The prices used for the different cuts, expressed as GBP/kg are obtained from Sainsbury's (2020a, 2020b, 2020c, 2020d), as shown in Table 8.6. These prices are applied in the model in the same fashion as in a revenue allocation model, with the cheaper cuts receiving a higher share of live animal weight, energy use, waste production, etc., than the more expensive ones.

Table 8.6. Prices for chicken cuts.

Pork cut	Price (GBP/kg)
Wings	1.7
Breast	5.0
Drumstick	1.7
Thigh	1.8

Turkey

The mass balance for turkey slaughtering is obtained from Miller (1968), as shown in Table 8.7. The Big Climate Database does not require modelling different turkey cuts and for this reason only average turkey meat is considered as the determining product in this production process. Use of water, electricity and natural gas is obtained from Blonk (2015), assuming the same values as for chicken slaughtering, per tonne live weight. Production of wastewater is assumed equal to the volume of water used.

Table 8.7. Mass balance for turkey slaughtering.

Flow	Tonne
Inputs	
Live animal	1
Outputs	
Meat, lean	0.615
Bone	0.270
Skin	0.091
Loss	0.021

Lamb

The mass balance for lamb slaughtering is obtained from European Commission (2017), distributing the live animal weight into carcass and by-products as shown in Table 8.8. The Big Climate Database does not require modelling different lamb cuts and for this reason only average lamb meat is considered as the determining product in this production process. Use of water, electricity and natural gas is obtained from Blonk (2015), assuming the same values as for pig slaughtering, per tonne live weight. Production of wastewater is assumed equal to the volume of water used.

Table 8.8. Mass balance for lamb slaughtering.

Flow	Tonne
Inputs	
Live animal	1
Outputs	
Meat	0.44
Bones	0.04
Fat	0.06
Category 3 slaughter by-products	0.13
Hides and skins	0.14
Category 1 and 2 material and waste	0.19

Duck, goose, hare, rabbit

The inventories for duck, goose, hare and rabbit are approximated by that of average chicken. The latter is equivalent to treating all chicken cuts with a mass-based allocation.

Wild game

Wild game includes pheasant and pigeon. This is considered as a constrained source of meat and for this reason an increase in demand for these products will induce consumption of the marginally-affected source of meat. In The Big Climate Database this is considered to be chicken, which is the closest species for which inventory data are available in the database.

8.2 Fish processing

The following tables show the edible portion of animal and the electricity use for filleting/processing of marginal species farmed in aquaculture, with the respective references. The non-marginal species are modelled as affecting the production volume of one of the marginal species in the same fish category (freshwater fish in **Table 8.9**, marine fish in **Table 8.10**, mollusc and shell fish in **Table 8.11**). The by-product fish offal (the non-edible portion) is treated to produce fish meal (84%) and fish meal (16%) (Silva et al. 2018).

Table 8.9. Freshwater fish: edible portion and electricity use for filleting.

Freshwater fish	Edible portion (%)	Source of edible portion's data	Electricity (kWh/kg)	Source of electricity data
Bream	0.36	FAO (1989)	0.076	Nielsen PH (2003)
Burbot	As Tilapia	FAO (1989)	0.076	Nielsen PH (2003)
Charr	As Trout	FAO (1989)	0.076	Nielsen PH (2003)
Perch	0.57	FAO (1989)	0.076	Nielsen PH (2003)
Pike	As Perch	FAO (1989)	0.076	Nielsen PH (2003)
Pikeperch	As Perch	FAO (1989)	0.076	Nielsen PH (2003)
Tilapia	0.37	FAO (1989)	0.076	Nielsen PH (2003)
Trout	0.50	FAO (1989)	0.076	Nielsen PH (2003)
Whitefish	As Tilapia	FAO (1989)	0.076	Nielsen PH (2003)

Table 8.10. Marine fish: edible portion and electricity use for filleting.

Marine fish	Edible portion (%)	Source of edible portion's data	Electricity (kWh/kg)	Source of electricity data
Cod	0.34	FAO (1989)	0.076	Nielsen PH (2003)
Garfish	As Tilapia	FAO (1989)	0.076	Nielsen PH (2003)
Halibut	As Salmon	FAO (1989)	0.076	Nielsen PH (2003)
Herring	0.46	FAO (1989)	0.076	Nielsen PH (2003)
Mackerel	0.54	FAO (1989)	0.076	Nielsen PH (2003)
Plaice	0.34	FAO (1989)	0.076	Nielsen PH (2003)
Pollock	0.36	FAO (1989)	0.076	Nielsen PH (2003)
Saithe (dark)	0.34	FAO (1989)	0.076	Nielsen PH (2003)
Salmon	0.50	FAO (1989)	0.076	Nielsen PH (2003)
Salmon (wild)	0.50	FAO (1989)	0.076	Nielsen PH (2003)
Tuna	0.30	FAO (1989)	0.076	Nielsen PH (2003)

Table 8.11. Mollusc and shell fish: edible portion and electricity use for filleting/processing.

Freshwater fish	Edible portion (%)	Source of edible portion's data	Electricity (kWh/kg)	Source of electricity data
Mollusc				
Octopus	As Mussels	-	-	-
Oyster (whole)	1***	-	0.015**	Williamson et al. (2015)
Mussel (whole)	1***	-	-	-
Shell fish				
Crab (whole)	-	-	-	-
Crayfish	As Shrimp	FAO (1989)	0.26	Nielsen PH (2003)
Lobster	As Shrimp	FAO (1989)	0.26	Nielsen PH (2003)
Prawn (giant tiger)	0.40	FAO (1989)	0.26*	Nielsen PH (2003)
Shrimp	0.33	FAO (1989)	0.26*	Nielsen PH (2003)

* It includes electricity used for peeling. Boiling requires 0.035 GJ of natural gas per kg of product (Nielsen 2003).
** Average between bottom cage and floating raft electricity use per kg half-shell oyster.
*** The product is assumed as sold with shell.

8.3 Dairy

Cow milk

The mass balance for cow milk processing in a dairy to produce whole, semi-skimmed and skimmed milk is obtained from the Danish LCA Food Database (Nielsen et al. 2003a). Cream is obtained as a dependent co-product, which in the model substitutes butter. Inputs of auxiliary materials such as cleaning chemicals, electricity and thermal energy are obtained as arithmetic averages from three studies (Hospido et al. 2003; Djekic et al. 2014; González-García et al. 2013). While the amount of cream co-product is specific to the final product (whole milk, semi-skimmed milk, skimmed milk), inputs of materials and energy are considered the same for all three milk products.

Goat milk
No specific inventory data for goat milk processing were found. This product is inventoried with the same dairy processing data as cow whole milk.

Cheese
Two types of cheese are included in The Big Climate Database: soft cheese and hard cheese. The former is modelled with data from Djekic et al. (2014), reporting figures for seven dairies in Serbia, given as ranges from which the arithmetic average is used. Cheese manufacturing co-produces whey and cream, however these are not reported in the mentioned source. In order to close the mass balance, the mass of these co-products is approximated with data for yellow cheese production from the Danish LCA Food Database (Nielsen et al. 2003b), assuming that they are produced in proportion to the milk input. Hard cheese is modelled with data from mature cheese production in Portugal, reported by González-García et al. (2013).

Butter
Butter is a dependent co-product from milk processing and as such it is considered constrained. Based on personal communications with ARLA Foods, the marginal demand for butter results in an increased production of 75% palm oil and 25% cow milk from the farm (in wet weight).

Yogurt
The inventory for yogurt production from cow milk from the farm is obtained from Djekic et al. (2014), reporting figures for seven dairies in Serbia, given as ranges from which the arithmetic average is used.

Milk and cheese powders
Although these products are not part of the 500 list, they are widely used by many listed products, as ingredients. The inventory for milk powder production, including the mass and energy balance, is based on Dalgaard and Schmidt (2014). The input of milk is assumed as cow milk from the farm. The inventory for cheese powder is approximated with the data for milk powder, where a lower water evaporation requirement is taken into account. While milk is assumed to be dried from around 10% solids to 96% solids, cheese is assumed to be dried from 50% solids to the same final value of 96%. Inputs of energy and water are asumed proportional to the weight of water to evaporate, while the milk input is established from the dry mass balance.

8.4 Oils and fats
The inventory of rapeseed oil and sunflower oil are obtained from Schmidt (2015b), while palm oil is obtained from Schmidt and De Rosa (2020). The inventory data describing the rapeseed and sunflower oil production system have been updated to the reference year 2016 for consistency with the palm oil data in Schmidt and De Rosa (2020). These updates include updating crop yields, fertiliser inputs and links to EXIOBASE as background database.

Margarine
The inventory for margarine is based on Nilsson et al. (2010), reporting recipes and manufacturing data for products sold in France, Germany and the UK. The recipe for margarine sold in Germany is chosen, as it has

the closest oil content compared to the product to be modelled in the database. Inputs of energy and tap water for manufacturing are calculated as an arithmetic average of the three products.

8.5 Cereal and grain products

Rice, bulgur, kamut

Data for white milled rice and parboiled rice are obtained from Blengini and Busto (2009), reporting primary data collected from the Vercelli rice district in northern Italy. No specific inventory data were found for bulgur production. Since the latter is a form of parboiled wheat, we approximate this process with the same data for parboiled rice from Blengini and Busto (2009). The same is assumed for precooked kamut wheat.

Flours

The database includes the following flours (not all of them cereal-based, though), either as final retail products or as ingredients for other food products:

- Rye flour
- Wheat flour
- Rye flour, wholemeal
- Wheat flour, wholemeal
- Maize flour
- Tapioca flour
- Chickpea flour
- Rice flour
- Coconut flour

The mass and energy balances for rye and wheat milling are obtained from Blonk (2015) and Nielsen et al. (2003c). Wholemeal rye and wheat flours are modelled with the same inventory data, assuming that there are no co-products (bran, etc.) as these are incorporated in the flour.

Data for Maize flour are obtained from Blonk et al. (2015) while the data for tapioca flour production is obtained from Damardjati et al. (1996) regarding the mass balance, while inputs of energy, etc., are obtained from Blonk (2015).

For chickpea flour, primary data regarding mass and energy balance are obtained from the Agribalyse database as implemented in the SimaPro software (ADEME 2020a).

No specific data were found for rice flour. The former is approximated from a mass balance perspective with data from Blengini and Busto for paddy rice milling, while energy and water use is obtained from Nielsen et al. (2003c).

Cereal kernels

No specific data were found on production of whole or cracked cereal kernels. These processes are approximated with the same data (mass balance, energy use, etc.) for the corresponding flour production (see Flours section).

Breakfast cereals and snacks

The database includes different types of breakfast cereals and cereal snacks:

- Corn flakes
- Müsli
- Müsli bar with chocolate
- Guldkorn
- Havrefras
- Oat flakes

The recipe for corn flakes is based on the corn content in the Kellogg' brands, namely 88%. This is assumed as corn flour. The remaining 12% is assumed as sugar and salt, which are the main following ingredients. All other inputs manufacturing energy, etc. are assumed as in production of biscuits by Noya et al. (2018).

A similar approach is taken with Guldkorn, for which the actual ingredients are available from the manufacturer. The manufacturing process is also assumed as in production of biscuits by Noya et al. (2018).

Havrefras production is approximated with the same recipe and manufacturing data as in corn flakes, where the main ingredient, corn flour, is replaced by whole wheat flour.

For müsli the inventory only includes the required ingredients, as specified in a commercial product (Open Food Facts 2018), while the müsli bar is modelled as containing 24% chocolate, based on specified ingredient data by Concito, while the remaining ingredients are scaled to 76% according to the inventory for müsli.

Finally, oat flakes are approximated with the same data as for oat flour production by Nielsen et al. (2003c).

8.6 Bakery

White bread

This inventory is used for the following products:

- White bread
- Tortilla bread
- Burger buns

These three products are modelled as a generic process for white bread production, including recipe (wheat flour, water, yeast, salt) and manufacturing process (electricity demand), is obtained from Espinoza-Orias et al. (2011), reporting figures for bread produced in the UK.

Rye bread

This includes inventories for the following products:

- Rye bread
- Rye crispbread
- Rye breadcrumbs with brown sugar

Rye bread production, including recipe (rye flour, water, barley malt extract, yeast, salt) and manufacturing process (electricity and natural gas demand), is obtained from Jensen and Arlbjørn (2014), reporting figures for bread produced in Denmark.

Rye crispbread is modelled as fresh rye bread subject to a second baking process. The amount of fresh bread needed per kg of final crispbread is calculated based on the moisture loss from fresh to crispbread (36.5% water moisture content in fresh bread, 2% in crispbread). The manufacturing energy requirements are assumed same as in fresh rye bread production as reported by Jensen and Arlbjørn (2014).

Finally, production of rye breadcrumbs with brown sugar is approximated with the same data for rye crispbread, considering that the final product contains 40% sugar. This is taken into account in the mass balance by considering a lower requirement of fresh rye bread.

Cakes

The Big Climate Database includes the following types of cakes:

- Danish pastry
- Plain cake
- Cream pastry, layer cake
- Truffle
- Æbleskiver
- Nougat

The first three products use the same inventory data for ingredients (recipe with 14 ingredients) and manufacturing process (electricity, natural gas), namely for a whole cake produced in the UK, as reported by Konstantas et al. (2019).

The truffle product considers a home-cooking recipe for 'romkugler' (ARLA 2020), while the energy requirements for baking are obtained from the Agribalyse database (ADEME 2020b).

For Æbleskiver, the recipe also corresponds to a home-cooking recipe, obtained from Nordic Food Living (2019). The mass balance estimates that 62% of the water in ingredients is evaporated during baking, resulting in higher inputs of fresh ingredients per unit of final product. Manufacturing energy demand is approximated with data for average cakes as reported by Konstantas et al. 2018. The same approach is taken for nougat, based on a home-cooking recipe from German cooking (2016).

Biscuits

Two inventories, for biscuits and wholemeal biscuits are included in the database. Both are based on a study on gluten-free biscuits produced in the UK (Noya et al. 2018), adapted as follows:

- For average biscuits, the mass of ingredients oat, maize and rice flour are substituted by the same amount of wheat flour.
- For wholemeal biscuits, the above-mentioned ingredients are substituted by wholemeal wheat flower.

8.7 Prepared and preserved foods

This section includes a wide variety of food products, in terms of both composition and manufacturing, such as:

- Pre-cooked food and ready meals, such as pizza, dry noodles, soups, sushi or falafel.
- Confectionery and candy, including products as diverse as chocolate, sugar, fruit gums or marzipan.
- Processed fruits and vegetables, such as canned vegetables, marmalade and nuts.
- Processed meats such as sausages, hams and salami.
- Processed fish and seafood, from pickled herring to fish pudding and fiskeboller.
- Seasonings ranging from salt and vinegar to mayonnaise and ketchup.

It is not feasible in this report to address each of these categories in detail, let alone each particular product. Here we only provide an overview of the approach and main data sources used to build inventories for production.

The preferred but unfortunately less frequent situation is that inventory data can be extracted from published LCA studies on the same or a reasonably similar product. Examples of such cases in the database are constituted by pizza (DEFRA 2009), chocolate (Recanati et al. 2018), pork sausage (Davis and Sonesson 2008) or ketchup (Andersson et al. 1998), among others.

In most cases, though, the inventory is built by means of the following approach:

- Defining a recipe
- Performing a mass balance
- Adding manufacturing inputs (energy, auxiliary materials, etc.)

Recipes are obtained, if possible, from industrial products, however this is not always possible, since ingredient declarations often contain only a list, or the content of main ingredients only. For this reason, in many cases ingredients in the database are defined and quantified based on home-cooking recipes available in various websites. Quantification of the recipe often requires conversions from different volumetric units, such as tablespoons or cups, or others such as ‘1 large onion’ to mass, which is done applying available densities and average weights of different foods.

The second step consists of a mass balance for the cooking or manufacturing process, considering inputs of ingredients and outputs of final product, waste and if applicable, water evaporation. Often a dry mass balance is required for these calculations, especially for cooked products, as this allows us to account for the evaporation losses. Waste is quantified as the input of ingredient minus losses through e.g. peeling.

Manufacturing inputs most commonly includes energy use (electricity, fuels). These are often taken as equal to similar products. Another option is to use Agribalyse data for such processes as boiling (ADEME 2020c), deep frying (ADEME 2020d), oven baking (ADEME 2020e) or freezing (ADEME 2020f).

8.8 Alcoholic beverages

Wine

The Big Climate Database provides an average inventory for wine production, which is not specific of any particular country or type of wine. The figures for each flow are obtained as the arithmetic average for the different inputs (grapes, energy, chemicals, energy carriers, etc.) and outputs (by-products, waste, etc.) reported in a total of 11 LCA studies addressing wine production in Italy, Spain, New Zealand, Portugal and Canada (Aranda et al. 2005; Gazulla et al. 2010; Vázquez-Rowe et al. 2012, 2013; Point et al. 2012; Ardente et al. 2006; Benedetto 2013; Carta 2009; Bosco et al. 2011; Barry 2011; Neto et al. 2013).

Beer

The Big Climate Database provides an average inventory for beer production, which is not specific of any particular country or type of beer. The figures for each flow are obtained as the arithmetic average for the different inputs (cereal grains, energy, chemicals, energy carriers, etc.) and outputs (by-products, waste, etc.) reported in a total of six LCA studies addressing beer production in US, Italy, Greece, Spain, Denmark and the UK (The Climate Conservancy 2008; Cordella and Santarelli 2008; Koroneos et al. 2005; Novozymes 2009; Hospido et al. 2005; Amienyo and Azapagic 2016).

Cider

We did not find specific inventory data for production of cider. This process was approximated based on ingredients for a soft drink (Amienyo et al. 2012), except sugar, which is specifically calculated to account for the sugar content in the final product plus losses through fermentation to achieve 4.5% ethanol content in the final product. Energy use for manufacturing is also approximated with data for soft drinks.

Spirits

Production of all distilled alcoholic beverages in the database are approximated with data from production of Whisky in the UK, as reported by Amienyo (2012).

Brandy

Production of brandy is approximated in the database with data from whisky production (Amienyo 2012), where the raw material for whisky (cereals grains) is replaced by wine. The amount of wine required as raw material is estimated based on the alcohol content of wine (9.5% of dm) and that of brandy (32% of dm).

Sherry

Production of sherry is approximated in the database as a mixture of brandy and wine, where brandy is taken here to represent the distilled spirit from grapes that is added to fortify the wine. The mixture is estimated as 73% wine and 27% brandy, in order to provide an alcohol content of 15.9% by weight in the final product. Since brandy has 32% alcohol by weight instead of 95% for a pure distilled spirit, the necessary mass of brandy in the sherry mixture is higher than if actual pure spirit was considered in the model.

Whisky cream

The recipe for whisky cream, including whisky, sugar and milk cream as main ingredients, is based on various source, as defined in Weidema et al. (2016). Energy used in the manufacturing process is assumed the same as in a carbonated soft drink as reported by Amienyo et al. (2012)

Alcoholic soda

The recipe for alcoholic soda includes 4% alcohol by weight and 10% sugar. The former is modelled as whisky with 33.4% alcohol by weight. The remaining ingredients and manufacturing energy are assumed as in a carbonated soft drink from Amienyo et al. (2012). Water is used as balancing ingredient.

8.9 Non-alcoholic beverages

Carbonated water

The inventory for production of carbonated bottled water is approximated with that for a soft drink according to Amienyo et al. (2012), where all ingredients other than water and carbon dioxide are omitted.

Soft drink

A generic soft drink recipe (water, sugar, carbon dioxide, citric acid, additives) and production process is obtained from Amienyo et al. (2012), with data originating in the UK.

Icetea

The recipe for icetea is based on ingredients declared by Concito and Nemlig (2020b). The manufacturing process is approximated with data for a soft drink (Amienyo et al. 2012).

Energy drink

A generic recipe for an energy drink has been estimated based on the content in sugar, vitamins, caffeine, taurine and glucoronolactone in a Red Bull drink (Higgins et al. 2010), while remaining ingredients and other inputs to the production process are approximated with data for a soft drink (Amienyo et al. 2012).

Tea

The inventory for production of tea is based on two studies, the first one representing tea production in Iran (Soheili-Fard et al. 2018) while the second one represents tea processing in India, Indonesia and Kenya and packaging in the UK (Jefferies et al. 2012). The inventory data (input of tea leaves, energy use) are obtained as the arithmetic average from these two studies.

Coffee

Coffee is included in The Big Climate Database in two formats:

- Instant coffee
- Roasted ground coffee

The inventory for conversion of green coffee beans to these two products is based on the study by Humbert et al. (2009), describing these two production processes in UK (instant coffee) and Spain (roasted ground coffee). The inventory includes inputs of coffee beans, water, electricity and natural gas.

Fruit juices

Original inventory data for fruit juice production have been found for orange juice produced in Spain (Jungbluth 2013) and apple juice produced in Iran (Khanali et al. 2020). Besides these two, the following products are also included in the database:

- Fruit juice, mixed, sweetened, concentrated
- Elderberry juice, sugar added
- Smoothie, strawberry and blueberry

Production of fruit juice, mixed, sweetened, concentrated, is modelled as orange juice, where the type of fruit used as raw material is changed to 25% each of: apple, orange, pineapple and banana. In addition, 0.41 kg sugar/L product is considered, based on the nutritional composition of the final product. The same approach is used for elderberry juice, where the only fruit considered as raw material is elderberry. For the smoothie model, also the manufacturing data are taken from orange juice production. The recipe, however, is obtained from a slightly different product (Nemlig 2020b), declaring the type (apples, bananas, blackberries, grapes, oranges, strawberries and raspberries) and number of fruit pieces used to produce 0.15 L of smoothie. This is roughly converted to mass by means of assumed average weights of fruit pieces, e.g. 85 g for an average apple. Based on the input of fruit and the output of smoothie the amount of organic waste is calculated.

Milk substitutes

The Big Climate Database includes inventories for production of the following vegetable-based milk substitutes:

- Soy milk
- Almond milk
- Rice milk
- Pea milk
- Oat milk

The inventory for soy milk production is based on several sources: the amount of soybean is obtained from Birgersson et al. (2009) and energy consumption is obtained from Grant et al. (2018). The amount of okara or soy pulp by-product is obtained from Pérez (2018), while water use is quantified in order to close the mass balance.

For almond milk produced from de-hulled almonds, the mass balance is obtained from Pereira (2019), while the energy consumption is obtained from Winans et al. (2020). These same data are used for the inventory of rice milk production, for which no specific data were found. Only the raw material is replaced (rice instead of almonds).

Data on oat milk production is obtained from a study on several products of the Oatly brand, performed by the Swedish Institute SIK (SIK 2013).

Pea milk production is approximated with data from oat milk production as reported by SIK (2013), where the ingredients are changed according to Ripple Foods’ pea drink (Open Food Facts 2020).

9 Life cycle inventory: Packaging

9.1 Packaging production

The Big Climate Database includes a total of 71 packaging datasets, which are used to cover the packaging of the 500 products. The reference flow in all these packaging datasets is 1 kg (or 1 L) of packaged product rather than of packaging material. Products are seldom packaged with a single format or material; for some of them a typical format or material prevails, for example wine, which is most commonly packaged in 75 cl glass bottles, while other products vary in packaging material and size. Beer, for example, is commonly found in different sizes and using either aluminium cans, steel cans or glass bottles. In these cases of various packaging possibilities, the choice has been made by means of a qualitative judgement by the authors regarding which material is most likely to be used. An exception to this in the database is soft drinks, for which the data used consists of a weighted average of packaging materials used in the UK market: PET, aluminium and glass (Amienyo et al. 2012). Besides primary packaging, secondary packaging is also included in some cases, depending on the availability of such data in each specific case.

The data sources used to quantify the amount and type of packaging materials include the following:

- LCA studies of food products where the packaging of the final product is included. Often the same study is used to build the inventory for product manufacturing and for product packaging. Some examples of this are rice (Blengini and Busto 2009) and pasta (Bevilacqua et al. 2007).
- LCA studies of food packaging. Some examples are chewing gum (Fernandez et al. 2008) and eggs (Zabaniotou and Kassidi 2003).
- Actual weighting by the authors of primary packaging materials. This is done, for example, for soy sauce, canned tomato, olives and marmalade, among others.
- Packaging specifications found on the internet for certain commercial products. This includes, for example, chocolate spread (data from the Nutella brand) and ketchup (data from the Heinz brand).
- Primary packaging mass ratios applied in the French Agribalyse database for products whose main packaging material is LDPE, cardboard, or PP, as shown in appendix 17 of Asselin-Balençon et al. (2020).

Each product in the database has been assigned one of the 71 packaging datasets available. As already mentioned, in some cases there is a direct match between the product and its packaging, such as for rice and pasta above, however in most cases the assignment of a certain packaging dataset has been made considering the closest match available. For example, the packaging dataset defined for fresh bread, based on Silvenius et al. (2011) has also been assigned to such products as breadcrumbs, burger buns, tortilla bread and crispbread, among others.

9.2 Packaging disposal

For each type of packaging material, an end-of-life scenario, representative of Danish conditions, has been established, as shown in Table 9.1. All recycling and disposal activities are included in the model by means of the closest Exiobase activities in Denmark, while primary data for glass bottle reuse (including bottle washing, etc.) is obtained from Schmidt (2005), reflecting this particular scheme in Denmark.

Table 9.1. Packaging disposal scenario.

Material	Reuse	Recycling	Incineration
Glass bottles (wine, spirits)	50%	50%	
Glass bottles (beer, soft drinks, water)	100%		
Glass jars		100%	
Aluminium (cans)		100%	
Aluminium (other)			100%
Plastics (PET, PP, HDPE, LDPE, PS, Nylon, undefined plastic)		50%	50%
Plastics (PVC)			100%
Paper and cardboard		50%	50%
Steel (cans)		95%	5%
Steel (other)		10%	90%
Tinplate		100%	
Wood		100%	
Cork			100%
Other materials			100%

10 Life cycle inventory: Retail

10.1 Storage conditions

Three storage conditions, regarding temperature, are considered in The Big Climate Database for wholesale markets and supermarkets:

- Ambient
- Cooled
- Frozen

Concito has not specified storage conditions for all products in the database. In the absence of specific information, the choice of storage conditions has been made by the authors based on their own judgement.

10.2 Storage in wholesale markets

Primary data for storage in wholesale markets is based on the Danish LCA Food database, providing an estimate of electricity and heat consumption, in MJ per kg per day for products stored at ambient temperature (Nielsen et al. 2003d), as well as cool and frozen (Nielsen et al. 2003e). In The Big Climate Database it is assumed that all products are stored during 3 days.

10.3 Storage in supermarkets

Primary data for storage in retail markets originates from several sources, namely the Danish Food database (Nielsen et al. 2003f), providing estimates of electricity and heat consumption, in MJ per kg per day , for products stored in ambient, cool and frozen conditions, secondly the study by Milà i Canals et al. (2007), suggesting typical storage times for each type of storage, and finally the study by DEFRA (2009), from which emission factors for refrigerants are calculated.

Energy consumption factors in a small retail store from Nielsen et al. (2003f) are taken for pasta, milk and pommes frites, as models for products stored under ambient, cooling and frozen conditions, respectively. Emissions of R404 refrigerant from cooling cabinets and freezers are estimated based on leakage data per kg cooled/frozen food in DEFRA (2009). However, instead of considering R404A as refrigerant we choose R449A, as the former is to be banned due to its high global warming potential. R449A is one of the likely substitutes with a lower global warming potential, consisting of a mixture of 4 gases: R32, R125, R134a and R1234yf. The refrigerants are quantified assuming that cooled products are stored 2 days and frozen products 15 days (Milà i Canals et al. 2007).

11 References

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ADEME (2020f) Freezing; of fresh ground beef, industrial production; French production mix, at plant;1 kg of frozen ground beef (POUi). Dataset retrieved from AGRIBALYSE v3.0: the French agricultural and food LCI database.

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Appendix 1: Dry matter and protein content of crops

Table 0.1. Dry matter and protein contents in crops.

	Dry matter coeff.	Reference	Protein content in wet weight crops	source:
Almonds, with shell	0.95	USDA (2021)	0.200	USDA (2021)
Anise, badian, fennel, coriander	0.85	GDV (2021)	0.010	USDA (2021)
Apples	0.14	USDA (2021)	0.026	USDA (2021)
Apricots	0.14	USDA (2021)	0.014	USDA (2021)
Areca nuts	0.95	Assumed as almonds	0.200	as almonds
Artichokes	0.22	USDA (2021)	0.033	USDA (2021)
Asparagus	0.08	USDA (2021)	0.012	USDA (2021)
Avocados	0.27	USDA (2021)	0.020	USDA (2021)
Bambara beans	0.85	Assumed as peas	0.218	as peas
Bananas	0.25	USDA (2021)	0.011	USDA (2021)
Barley	0.85	Moeller et al. (2005)	0.092	Moeller et al. (2005)
Beans, dry	0.91	CCOS (2015)	0.255	USDA (2021)
Beans, green	0.33	USDA (2021)	0.129	USDA (2021)
Berries nes	0.15	Assumed as blueberries	0.007	as Bluesberries
Blueberries	0.15	USDA (2021)	0.007	USDA (2021)
Brazil nuts, with shell	0.95	Assumed as almonds	0.143	USDA (2021)
Broad beans, horse beans, dry	0.86	Møller et al. (2005)	0.267	USDA (2021)
Buckwheat	0.90	USDA (2021)	0.133	USDA (2021)
Cabbages and other brassicas	0.08	USDA (2021)	0.013	USDA (2021)
Canary seed	0.91	CCOS (2015)	0.193	Assumed as sunflower seeds
Carobs	0.98	USDA (2021)	0.045	Papaefstathiou et al. (2018)
Carrots and turnips	0.12	USDA (2021)	0.009	USDA (2021)
Cashew nuts, with shell	0.95	Assumed as almonds	0.182	USDA (2021)
Cashewapple	0.85	Morton (1987)	0.001	USDA (2021)
Cassava	0.36	Chávez et al. (2008)	0.039	USDA (2021)
Cassava leaves	0.08	as spinach	0.070	USDA (2021)
Castor oil seed	0.92	Assumed as rapeseed	0.186	Assumed as rapeseed
Cauliflowers and broccoli	0.09	USDA (2021)	0.019	USDA (2021)
Cereals, nes	0.85	Assumed as wheat	0.098	USDA (2021)
Cherries	0.19	USDA (2021)	0.010	as Cherries. Sour
Cherries, sour	0.19	USDA (2021)	0.010	USDA (2021)
Chestnut	0.95	Assumed as almonds	0.051	USDA (2021)
Chick peas	0.85	Assumed as peas	0.255	as beans
Chicory roots	0.24	Assumed as potatoes	0.014	USDA (2021)
Chillies and peppers, dry	0.88	GDV (2021)	0.010	USDA (2021)
Chillies and peppers, green	0.18	USDA (2021)	0.104	USDA (2021)
Cinnamon (canella)	0.82	as Nutmeg	0.010	USDA (2021)
Cloves	0.82	as Nutmeg	0.010	USDA (2021)
Cocoa, beans	0.60	ICCO (2020)	0.200	USDA (2021)
Coconuts	0.54	NRI (1995)	0.033	USDA (2021)
Coffee, green	0.50	PDG (2017)	0.000	USDA (2021)
Cow peas, dry	0.85	Assumed as peas	0.218	as peas
Cranberries	0.15	Assumed as blueberries	0.005	USDA (2021)
Cucumbers and gherkins	0.04	USDA (2021)	0.006	USDA (2021)
Currants	0.15	Assumed as blueberries	0.014	USDA (2021)
Dates	0.67	USDA (2021)	0.300	USDA (2021)
Eggplants (aubergines)	0.08	USDA (2021)	0.010	USDA (2021)
Figs	0.21	USDA (2021)	0.008	USDA (2021)

Fonio	0.85	Assumed as wheat	0.067	USDA (2021)
Fruit, citrus nes	0.13	Assumed as oranges	0.007	Assumed as oranges
Fruit, fresh nes	0.22	as Apple	0.026	as Apple
Fruit, pome nes	0.15	Assumed as plums	0.026	as apples
Fruit, stone nes	0.12	as peaches	0.009	as peaches
Fruit, tropical fresh nes	0.17	as Mangoes	0.008	as Mangoes
Garlic	0.41	USDA (2021)	0.064	USDA (2021)
Ginger	0.87	GDV (2021)	0.010	USDA (2021)
Gooseberries	0.15	Assumed as blueberries	0.009	USDA (2021)
Grain, mixed	0.85	Assumed as wheat	0.098	Assumed as wheat
Grapefruit (inc. pomelos)	0.09	USDA (2021)	0.006	USDA (2021)
Grapes	0.19	USDA (2021)	0.007	USDA (2021)
Groundnuts, with shell	0.95	Assumed as almonds	0.200	as almonds
Hazelnuts, with shell	0.95	USDA (2021)	0.167	USDA (2021)
Hempseed	0.92	Assumed as rapeseed	0.225	Wang & Xiong (2019)
Hops	0.40	Assumed	0.010	USDA (2021)
Jojoba seed	0.92	Assumed as rapeseed	0.193	as sunflowerseeds
Kapok fruit	0.53	www.fruitsinfo.com/	0.168	www.fruitsinfo.com/
Karite nuts (sheanuts)	0.85	Assumed	0.200	as almonds
Kiwi fruit	0.16	USDA (2021)	0.014	USDA (2021)
Kola nuts	0.95	Assumed as almonds	0.200	as almonds
Leeks, other alliaceous vegetables	0.09	USDA (2021)	0.015	USDA (2021)
Lemons and limes	0.11	USDA (2021)	0.011	USDA (2021)
Lentils	0.85	Assumed as peas	0.246	USDA (2021)
Lettuce and chicory	0.04	USDA (2021)	0.009	USDA (2021)
Linseed	0.92	Assumed as rapeseed	0.207	INRA-CIRAD-AFZ (2020)
Lupins	0.91	Hinton (2007)	0.362	USDA (2021)
Maize	0.86	Moeller et al. (2005)	0.083	Moeller et al. (2005)
Maize, green	0.67	INRA-CIRAD-AFZ (2020)	0.062	INRA-CIRAD-AFZ (2020)
Mangoes, mangosteens, guavas	0.17	USDA (2021)	0.008	USDA (2021)
Maté	0.40	Assumed	0.010	USDA (2021)
Melons, other (inc.cantaloupes)	0.10	USDA (2021)	0.005	USDA (2021)
Melonseed	0.92	Assumed as rapeseed	0.193	as sunflowerseeds
Millet	0.83	CCOS (2015)	0.110	USDA (2021)
Mushrooms and truffles	0.08	USDA (2021)	0.030	USDA (2021)
Mustard seed	0.92	Assumed as rapeseed	0.193	as sunflowerseeds
Nutmeg, mace and cardamoms	0.82	GDV (2021)	0.010	USDA (2021)
Nuts, nes	0.95	Assumed as almonds	0.200	as almonds
Oats	0.85	Moeller et al. (2005)	0.087	Moeller et al. (2005)
Oil palm fruit	0.47	Weng (1999)	0.022	Weng (1999)
Oilseeds nes	0.92	Assumed as rapeseed	0.186	Assumed as rapeseed
Okra	0.10	USDA (2021)	0.019	USDA (2021)
Olives	0.40	Arij (2017)	0.010	USDA (2021)
Onions, dry	0.10	Assumed	0.011	USDA (2021)
Onions, shallots, green	0.20	USDA (2021)	0.021	Assumed
Oranges	0.13	USDA (2021)	0.007	USDA (2021)
Papayas	0.12	USDA (2021)	0.005	USDA (2021)
Peaches and nectarines	0.12	USDA (2021)	0.009	USDA (2021)
Pears	0.16	USDA (2021)	0.004	USDA (2021)
Peas, dry	0.85	Moeller et al. (2005)	0.218	USDA (2021)
Peas, green	0.18	USDA (2021)	0.054	USDA (2021)
Pepper (piper spp.)	0.88	GDV (2021)	0.010	USDA (2021)
Peppermint	0.85	as coriander	0.010	as coriander
Persimmons	0.20	USDA (2021)	0.006	USDA (2021)
Pigeon peas	0.85	Assumed as peas	0.218	as peas
Pineapples	0.16	USDA (2021)	0.005	USDA (2021)

Pistachios	0.95	Assumed as almonds	0.200	USDA (2021)
Plantains and others	0.35	USDA (2021)	0.013	USDA (2021)
Plums and sloes	0.15	USDA (2021)	0.007	USDA (2021)
Poppy seed	0.92	Assumed as rapeseed	0.193	as sunflowerseeds
Potatoes	0.24	Moeller et al. (2005)	0.020	USDA (2021)
Pulses, nes	0.85	Assumed as peas	0.218	as peas
Pumpkins, squash and gourds	0.08	USDA (2021)	0.010	USDA (2021)
Quinces	0.22	Assumed as apple	0.004	USDA (2021)
Quinoa	0.85	Assumed as wheat	0.133	USDA (2021)
Rapeseed	0.92	Moeller et al. (2005)	0.186	INRA-CIRAD-AFZ (2020)
Raspberries	0.13	USDA (2021)	0.012	USDA (2021)
Rice, paddy	0.86	Moeller et al. (2005)	0.067	
Roots and tubers, nes	0.24	Assumed as potatoes	0.020	Assumed as potatoes
Rye	0.85	Assumed as wheat	0.070	USDA (2021)
Safflower seed	0.92	Assumed as rapeseed	0.193	as sunflowerseeds
Seed cotton	0.92	Assumed as rapeseed	0.220	INRA-CIRAD-AFZ (2020)
Sesame seed	0.92	Assumed as rapeseed	0.200	USDA (2021)
Sorghum	0.89	CCOS (2015)	0.106	USDA (2021)
Soybeans	0.95	Assumed as almonds	0.365	www.wikipedia
Spices, nes	0.88	as pepper	0.010	as pepper
Spinach	0.08	USDA (2021)	0.029	USDA (2021)
Strawberries	0.08	USDA (2021)	0.007	USDA (2021)
String beans	0.10	USDA (2021)	0.018	USDA (2021)
Sugar beet	0.22	Moeller et al. (2005)	0.010	assumed
Sugar cane	0.30	Preston (1988)	0.010	assumed
Sugar crops, nes	0.24	Assumed as sugar beet	0.010	assumed
Sunflower seed	0.92	Moeller et al. (2005)	0.193	USDA (2021)
Sweet potatoes	0.24	Assumed as potatoes	0.017	USDA (2021)
Tallowtree seed	0.92	Assumed as rapeseed	0.193	as sunflowerseeds
Tangerines, mandarins, clementines, satsumas	0.12	USDA (2021)	0.008	USDA (2021)
Taro (cocoyam)	0.93	Temesgen et al. (2017)	0.015	USDA (2021)
Tea	0.40	Assumed	0.010	USDA (2021)
Tomatoes	0.06	USDA (2021)	0.009	USDA (2021)
Triticale	0.85	Assumed as wheat	0.098	USDA (2021)
Tung nuts	0.95	Assumed as almonds	0.193	as sunflowerseeds
Vanilla	0.82	as Nutmeg	0.010	USDA (2021)
Vegetables, fresh nes	0.08	Assumed as Eggplants	0.010	Assumed as Eggplants
Vegetables, leguminous nes	0.18	as peas	0.054	as peas
Vetches	0.90	Assumed	0.280	Nguyen (2020)
Walnuts, with shell	0.95	USDA (2021)	0.152	USDA (2021)
Watermelons	0.09	USDA (2021)	0.006	USDA (2021)
Wheat	0.85	Moeller et al. (2005)	0.098	USDA (2021)
Yams	0.24	Assumed as potatoes	0.015	USDA (2021)
Yautia (cocoyam)	0.93	Temesgen et al. (2017)	0.015	USDA (2021)