Life cycle assessment of milk - National baselines for Germany, Denmark, Sweden and United Kingdom 1990 and 2012

Preface

This report presents a detailed life cycle inventory (LCI) and LCIA results on GHG emissions for milk produced in Germany, Denmark, Sweden and United Kingdom in 2012, as well as results for 1990. The current study has been conducted during 2015 and 2016, and it draws upon the methodology developed and documented in:

- Schmidt and Dalgaard (2012). National and farm level carbon footprint of milk – Methodology and results for Danish and Swedish milk 2005 at farm gate. Arla Foods, Aarhus, Denmark. http://lca-net.com/p/220

The underlying life cycle inventory (LCI) for the presented LCIA results for 1990 are documented in:

- Dalgaard and Schmidt (2012b). National carbon footprint of milk - Life cycle assessment of Danish and Swedish milk 1990 at farm gate. Arla Foods, Aarhus, Denmark
- De Rosa et al. (2013). National carbon footprint of milk - Life cycle assessment of British and German milk 1990 at farm gate. Arla Foods, Aarhus, Denmark

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1 Introduction

In their work with sustainability, Arla Foods focusses on tracking the environmental impact of their main raw material, raw milk, – both at farm level, and at the national level. Arla is using this information as baselines and benchmarks for their environmental goals, as a tool for individual milk farmers, and for gaining knowledge about the environmental impacts and how to mitigating impacts. The current report presents a detailed life cycle assessment of raw milk at farm gate in Germany, Denmark, Sweden and United Kingdom for 2012. Furthermore, the results are compared with results for 1990. The four countries represent the majority (>95%) of the supply of milk to Arla Foods (Schmidt and de Saxcé 2016). The life cycle inventory data for milk production in the four countries are also used as data inputs for the farm tool which Arla and their raw milk suppliers are using to calculate farm specific GHG emissions.

1.1 LCA of milk at Arla Foods

Life cycle assessment of milk at Arla foods started in 2011 with a study on Danish and Swedish milk produced in 2005. The developed model was intended for being used for obtaining national baselines as well as for being used to calculate carbon footprints of milk production on individual farms. The outcome of this study is published in:

- Schmidt J H, Dalgaard R (2012). National and farm level carbon footprint of milk – Methodology and results for Danish and Swedish milk 2005 at farm gate. Arla Foods, Aarhus, Denmark. http://lca-net.com/p/220
- Dalgaard R, Schmidt J H (2012a). National and farm level carbon footprint of milk – Life cycle inventory for Danish and Swedish milk 2005 at farm gate. Arla Foods, Aarhus, Denmark. http://lca-net.com/p/222
- Dalgaard R, Schmidt J H, Flysjö A (2014). Generic model for calculating carbon footprint of milk using four different LCA modelling approaches. Journal of Cleaner Production 73:146-153

In 2012, national baselines for Denmark and Sweden for 1990 were conducted (Dalgaard and Schmidt 2012b). The purpose of these older inventories were to have data for the reference year, to which Arla defines and benchmarks their environmental performance targets. In 2013, national baselines for Germany and United Kingdom were also established (De Rosa et al. 2013).

Concurrently with the establishment of national baselines, a tool to calculate carbon footprints of milk produced at farm level in Germany, Denmark, Sweden and United Kingdom has been developed. The background data (e.g. imported feed, electricity etc.) used in the tools, are from the national baselines. The tools are updated regularly with new background data, impact assessment data etc.

1.2 Purpose of the study

The aim of this study is to carry out a life cycle assessment of raw milk for the main countries in which Arla buys their milk. The results and data are used for:

- Providing inputs to the ongoing process of increasing the knowledge on the impacts and development in impacts of raw milk – and on how the impacts can be mitigated.
- Obtaining national baselines of raw milk to be used as benchmarks.
- The inventory data are used in Arla's farm calculator tool.
- The data feeds into Arla's corporate sustainability work on Profit and Loss Accounting (Schmidt and de Saxcé 2016).

In this report, only results for greenhouse gas emissions are presented.

1.3 Milk production in Germany, Denmark, Sweden and United Kingdom

In the following, characteristics of dairy production in each of the countries are briefly described.

Germany

Germany is the World's sixth largest milk producer with 30,500,000 tonnes delivered in 2012 (FAOSTAT 2014). In 2012, the average milk yield reached 7,280 kg/head/year and the number of milk-producing cows was 4,190,000 heads (Haenel et al. 2014). The production is based on intensive systems, where relatively high milk yields are obtained with a minimal use of land. Because of this practice, typical feed types include hardly any grazing. Instead, mixed diet contains maize and grass silages and grass-based diet consists of grass silage, both are supplemented with protein concentrates (FAO et al. 2014; Dämmgen et al. 2010). According to Statistisches Bundesamt (2013a), the main breeds in German herds are Holstein-Friesian (dairy breed, 54.6% of all cows in milk system), Fleckvieh (dual-purpose, 28.9%) and Red Holstein (dairy, 7.09%).

Denmark

In 2012, the dairy sector in Denmark produced 5,000,000 tonnes of milk. This makes Denmark the 29th largest milk producer in the world (FAOSTAT 2014). The milk yields in Denmark are high (8,507 kg/head/year), one of the highest in the world (Statistics Denmark 2014). Approximately 75% of dairy cows belong to Danish Holstein breed, followed by 12% of Danish Jersey. The protein and fat content in milk from Danish Jersey is higher than for the other races.

Sweden

Out of the four studied countries, Sweden has the smallest milk industry with 2,900,000 tonnes produced by approximately 350,000 cows (FAOSTAT 2014). Similar to Denmark, Sweden is one of the leading countries when it comes to the milk yields and in 2012 reached the average of 8,722 kg/head/year (Al-Hanbali et al. 2014). The high yield is obtained in intensive production systems, which in Sweden still include pasture in the cattle diet. Again, roughage is the main component of the feed (65-71% of dry matter intake, depending on the region; Henriksson et al. 2014). The most common dairy breeds are Swedish Holstein (51.8% of the dairy herd; WHFF 2012) and Swedish Red and White, together constituting the majority of the dairy cattle (Svensk Kvig Export 2015).

United Kingdom

In 2012, 2.20% of total global cow milk production originated from United Kingdom, making it world's tenth-largest producer (FAOSTAT 2014). The average milk yield in 2012 was 7,706 kg/head/year and around 1,800,000 cows belong to dairy herds (Webb et al. 2014a, 2014b). In the milk systems, the percentage of dual-purpose breeds is marginal and the main breeds belong to the group of black and white dairy cows (including Friesian, Holstein Friesian, British Friesian and Holstein breeds). Together, they account for approximately 32% of all British cows (Defra 2008). The most widespread, mixed feed consists of roughage (80%) with grass silage as the main component (FAO et al. 2014). Comparing to other countries described in this report, pasture is more significant in diet of British dairy herds.

2 Goal and scope of the study

The LCA is carried out in accordance with the ISO standards on LCA: ISO 14040 (2006) and ISO 14044 (2006). 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

This section documents the first phase of the LCA of palm oil at United Plantations Berhad (UP). 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.

2.1 Functional unit

The functional unit is 1 kg energy corrected milk (ECM). ECM is here defined as raw milk with 4.10% fat and 3.30% protein (Sjaunja et al. 1990). The flow of milk is converted to the functional unit by using the following formula (Sjaunja et al. 1990):

$$\mathrm{ECM} = \mathrm{milk} \cdot \frac{(0.383 \cdot \mathrm{fat\_cont} \cdot 100 + 0.242 \cdot \mathrm{protein\_cont} \cdot 100 + 0.7832)}{3.14}$$

Where:

ECM = energy corrected milk defined as raw milk with 4.10% fat and 3.30% protein
Milk = raw milk
Fat_cont = content of fat, fraction
Protein_cont = content of protein, fraction

2.2 Product system

Milk is produced in the cattle system. Generally, the cattle system can be divided into a milk system and a beef system. The milk system is optimised in order to produce milk and meat from surplus calves can be regarded as a by-product of the system. The beef system is characterised by having meat as the main product and no milk production.

In the milk system, the milking cows produce the milk. Approximately one time a year, the cow must have a calf for maintaining high milk production. Some of the heifer calves are raised to be milking cows to maintain the herd, while the surplus heifers are slaughtered. Generally, all bull calves are raised for slaughter. A heifer becomes a milking cow when it gives birth to its first calf.

Cattle have their feed from the plant cultivation system, i.e. plant material cultivated on arable or rangeland, or from the food industry. Feed from the food industry is most often by-products, e.g. molasses from sugar manufacturing or rapeseed meal from rapeseed oil manufacturing. But in some cases, feed is the main product in the food industry, e.g. soymeal from the soybean oil mill.

The plant cultivation system involves pastures as well as annual and perennial crops. Some cultivation requires significant inputs of mechanical energy (traction) and chemicals (fertilisers and pesticides), whereas others are more extensive. The food industry involves the processing of crops from the plant cultivation system.

The milk system, plant cultivation system and food industries are illustrated in Figure 2.1.

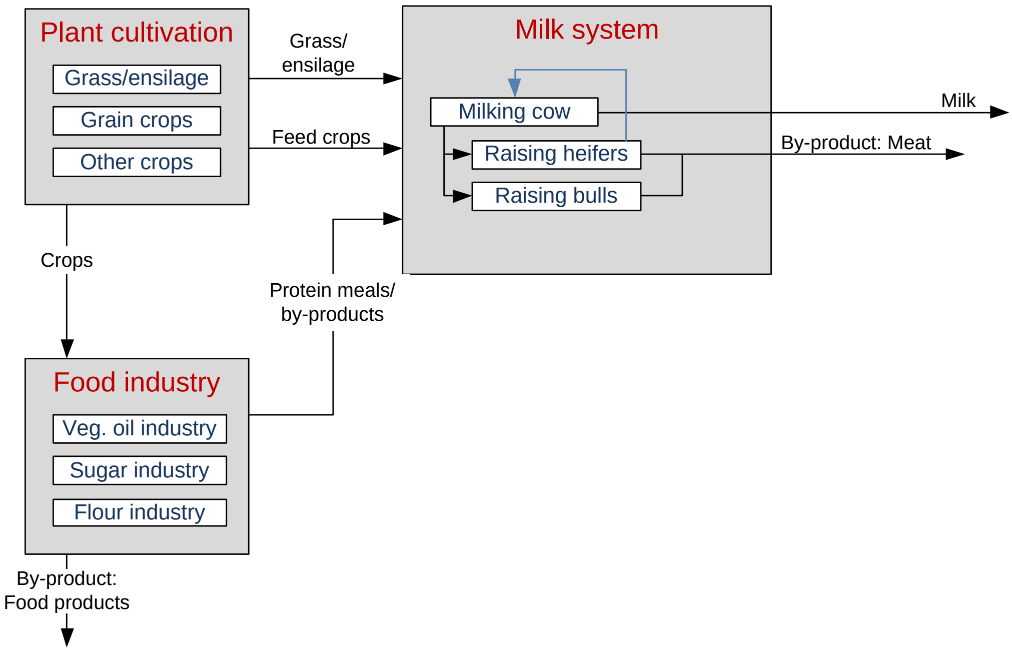

Figure 2.1: Overview of the milk production system. In addition to the shown product stages, there are also several other involved industry sectors, such as transportation, electricity generation, fuel production, fertiliser production etc.

When calculating the carbon footprint for milk, the major GHG-emissions from the milk system are related to methane (CH_4) from enteric fermentation and manure management, but also nitrous oxide (N_2O) emissions from manure management are important. The most important upstream contribution is related to the production of feed. Here nitrous oxide emissions from the field (from fertiliser application) and from the production of fertilisers are the major GHG-emissions. Other GHG-emissions in the system such as diesel for traction, electricity for the milking machinery etc. are generally less important. (Flysjö et al. 2011; Kristensen et al. 2011; Thomassen et al. 2008; Gerber et al. 2010).

2.3 Delimitation of time and geography

The current report presents a life cycle inventory (LCI) and carbon footprint results for milk production in Germany, Denmark, Sweden and United Kingdom in 2012. Furthermore. Carbon footprint results are presented for 1990. The life cycle inventory for 1990 is documented in the following two reports:

- **Dalgaard R and Schmidt J H (2012b)**, National carbon footprint of milk - Life cycle assessment of Danish and Swedish milk 1990 at farm gate. Arla Foods, Aarhus, Denmark.
- **De Rosa M, Dalgaard R and Schmidt J H (2013)**, National carbon footprint of milk - Life cycle assessment of British and German milk 1990 at farm gate. Arla Foods, Aarhus, Denmark.

The life cycle inventory includes the following of inventoried activities:

- Cattle system,
- Plant cultivation system,
- Food industry system, and
- General activities which are used in several other activities

The general activities, which are used in several other activities, include electricity, transport, fuels etc. The table below summarises which activities and countries that are included in the inventory of the cattle system, plant cultivation system, and food industry.

Table 2.1: List of inventoried cattle, plant cultivation and food industry activities in the current study.

Inventoried activities	BR	DE	DK	FR	MY/ID	SE	UA	UK	EU
Cattle system									
Milk system (cows, heifers and bulls)		X	X			X		X	
Beef system (cows, heifers and bulls)	X								
Plant cultivation system									
Permanent grass [roughage]	X	X	X			X		X	
Rotation grass [roughage]		X	X			X		X	
Roughage, maize ensilage		X	X			X		X	
Barley		X	X			X	X	X	X
Wheat		X	X			X		X	X
Oat		X	X			X		X	
Corn									X
Soybean	X								
Rapeseed									X
Sunflower				X					
Sugar beet		X	X			X		X	
Oil palm					X				
Food industries									
Palm oil mill [oil and kernel]					X				
Palm oil refinery [oil and free fatty acids]					X				
Palm kernel oil mill [oil and meal]					X				
Palm kernel oil refinery [oil and free fatty acids]					X				
Soybean oil mill [oil and meal]	X								
Soybean oil refinery [oil and free fatty acids]	X								
Rapeseed oil mill [oil and meal]									X
Rapeseed oil refinery [oil and free fatty acids]									X
Sunflower oil mill [oil and meal]				X					
Sugar mill [sugar, molasses, beet pulp]		X	X			X		X	
Flour mill [flour and wheat bran]									X
Malthouse [malt and malt sprouts]		X	X			X		X	
Brewery [Beer and brewer's grain]		X	X			X		X	
Bioethanol production [bioethanol and DDGS]									X
Milk powder production		X	X			X		X	
Milk replacer production		X	X			X		X	

2.4 LCA approach compliance with several guidelines/standards

A key challenge for Arla is that different methods for calculating the carbon footprint (CF) / LCA results are often used in the countries where Arla operates. Arla therefore needs a flexible tool that enables different types of modelling depending on the context. It should be possible to calculate the CF at farm level and national level according to the used practises in the given country, but it should also be possible to compare results between countries and to calculate the aggregated CF at corporate level.

Therefore, the life cycle assessment is modelled in a flexible framework, where it is possible to switch between different modelling assumptions and where different levels of completeness in data can be switched on and off. The included standards/guidelines are:

- **Consequential LCA (consistent interpretation of ISO 14040/44):** included suppliers are the most likely to be affected and allocation is avoided by substitution. The following standards/methodologies are followed: ISO 14044 (2006), Weidema et al. (2009). Further, the quality guideline for ecoinvent v3 (consequential version) is to a large extent followed (Weidema et al. 2013).
- **Attributional LCA (more normative interpretation of ISO 14040/44):** market average mixes of suppliers and allocation are carried out by use of allocation (economic). The assumptions regarding market average and economic allocation are consistently applied (as opposed for PAS2050 and IDF below). Further, the quality guideline for ecoinvent v3 (attributional version) is to a large extent followed (Weidema et al. 2013).
- **PAS2050** (PAS2050 2008; Dairy UK et al. 2010)
- **IDF guideline** (IDF 2010)

The features of the four standards/guidelines are summarised in the table below.

Table 2.2: Description of the key elements of the modelling in LCI in the applied modelling approaches/standards.

Elements in modelling	Description
ISO 14040/44: Consequential modelling (ISO 14040, 2006; ISO 14044, 2006; Weidema et al. 2011)	
Included suppliers	The included suppliers represent the actual production mix (ISO14044, section 4.3.3.1). This is interpreted as the actual affected suppliers by a change in demand. As default, the actual production mix is regarded as the average product mix where constrained suppliers are excluded (Weidema et al. 2009).
Multiple-output activities	Whenever possible, allocation should be avoided (ISO 14044, section 4.3.4.2). The reference product(s), i.e. the determining co-product(s) is determined, and the remaining co-products are regarded as by-products which can directly substitute other products or as material to treatment. All exchanges are ascribed to the reference product(s) including the avoided exchanges related to the displaced activities due to by-products.
Completeness	The applied cut-off criterion is 0%, i.e. all transactions in the product system are included. Some transactions are inventoried in detail whereas other are obtained a more generic data from LCI databases (ecoinvent) and input-output databases
Average/allocation: Attributional modelling (Weidema et al. 2011); ecoinvent v3 attributional version	
Included suppliers	The included suppliers represent the average market mix including constrained suppliers.
Multiple-output activities	Allocation is carried out for all co-products. It should be noted that allocation is only carried out for products for which there exist a market, i.e. allocation is not carried out between co-products and material to treatment. In such cases the allocation is carried out between the products at the point of substitution.
Completeness	The applied cut-off criterion is 0%, i.e. all transactions in the product system are included. Some transactions are inventoried in detail whereas other are obtained a more generic data from LCI databases (ecoinvent) and hybrid input-output databases
PAS 2050: Mixed consequential and attributional (PAS2050, 2008; Dairy UK et al. 2010)	
Included suppliers	The included suppliers represent the average market mix including constrained suppliers. This is not directly stated in the PAS 2050, but In PAS 2050 (2008, section 4.1) it is stated that attributional modelling should be applied unless otherwise specified. For electricity, the average electricity supply shall be applied.
Multiple-output activities	Whenever possible, allocation should be avoided (PAS 2050, 2008, section 8.1). CHP: when a company exports energy (then substitution), when energy is purchased from the energy system (then energy quality allocation; different for boiler based and turbine based CHPs), transport (physical causality allocation)
Completeness	The applied cut-off criterion is zero except the fact that capital goods are excluded (PAS 2050, section 6.3-6.4). Further, services are not included. This exclusion is not completely clear in PAS2050, but it has been assumed that services are generally excluded from inventories when capital goods are.
IDF guide to standard LCA methodology for the dairy industry: Mixed consequential and attributional (IDF 2010)	
Included suppliers	The included suppliers represent the average market mix including constrained suppliers. This is not directly stated in the IDF, but reference is made to PAS 2050 in the section on system boundaries (IDF 2010, section 5).
Multiple-output activities	Whenever possible, allocation should be avoided (IDF, 2010, section 6.3.1). Specific guidelines are provided for: Feed (economical allocation), milk/meat (specified formula), onsite CHP (substitution), exported manure (substitution). Further, it should be noticed that the raising of bulls for meat production as illustrated in Figure 2.1 is not part of the milk system, i.e. the export of small bulls for further raising for meat production are excluded from the inventory (allocated with factor = 0). (Flysjö 2012)
Completeness	The applied cut-off criterion is defined as <1% in IDF (2010, section 5.1), and a non-exhaustive list of activities is provided. IDF does not specifically exclude any groups of inventory items, as PAS2050 does. Therefore, the same level of completeness is applied in the IDF switch mode as for the ISO 14040/44 consequential and average/allocation attributional switch modes.

The different standards/guidelines above are explained and interpreted more in detail in Schmidt and Dalgaard (2012a).

2.5 Life cycle impact assessment

The current study only presents results for global warming. When translating GHG emissions into carbon dioxide equivalants, IPCC's global warming potential (GWP) has been used. The newest available emission factors from IPCC's fifths assessment report have been used (IPCC 2013). Therefore, the results in the current report are not directly comparable to carbon footprint of milk presented in the previous Arla reports (De Rosa et al. 2013; Schmidt and Dalgaard 2012a,b), where an older of IPCC's emission factors has been used (IPCC 2007).

3 General activities and data

This chapter documents the life cycle inventory data that surround the detailed inventoried product system – also referred to as the background system. This includes inventory data for electricity, fuels, burning of fuels, fertiliser, chemicals, transport and capital goods, services, and indirect land use changes (iLUC). For many inputs to the modelled milk system (foreground system), the same data as used in the calculation of Danish and Swedish national baselines for raw milk for 2005 are used. These data are described by Dalgaard and Schmidt (2012a).

3.1 Services (general)

These data have been modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

3.2 Capital goods (general)

These data have been collected for 2005 by Dalgaard and Schmidt (2012a) from ecoinvent Version 2 (Frischknecht et al. 2005). The same data have been applied here.

3.3 Electricity

The methodology used for the electricity in switch 1 is detailed described by Schmidt et al. (2011) and can be freely accessed here: http://www.lca-net.com/projects/electricity_in_lca/ The electricity generation in 2012 is obtained from the IEA website database (2012) and the predictions for 2020 from the European Commission (2010a, 2010b, 2010c, 2010d).

In Table 3.1, Table 3.2, Table 3.3 and Table 3.4 the electricity generation in Germany, Denmark, Sweden and United Kingdom is presented. For the switch ISO14040/44, i.e. consequential modelling, the affected suppliers are identified as the proportion of the predicted growth for each supplier on the period 2012-2020. The last column in the tables present the electricity used for switch 2-4 and data are from ecoinvent Version 3 (Weidema et al. 2013).

Table 3.1: Data for power generation in Germany 2012, predictions for 2020, and the applied electricity mixes for the four switches. Data are obtained from the IEA database (2012), European Commission (2010a) and ecoinvent Version 3 (Weidema et al. 2013).

Germany	Generation in 2012 TWh	Generation in 2020 TWh	Change in generation 2012-2020 TWh	Applied electricity mix in consequential modelling Switch 1	Applied electricity mix in attributional modelling Switch 2-4
Coal	287	260	-26.8	0	0.449
Oil	7.6	3.7	-3.9	0	0.015
Gas	77.6	132	54.7	0.437	0.164
Biomass	51.2	49.5	-1.7	0	0.014
Nuclear	99.5	0	-99.5	0	0.243
Hydro	27.8	20.0	-7.8	0	0.044
Wind	50.7	104	53.8	0.430	0.071
Geothermal	0	1.7	1.7	0.013	0
Solar	26.4	41.4	15.0	0.120	0
Marine	0	0	0	0	0
Total	**630**	**613**	**-14.6**	**1.00**	1.00

Table 3.2: Data for power generation in Denmark 2012, predictions for 2020, and the applied electricity mixes for the four switches. Data are obtained from the IEA database (2012), European Commission (2010b) and ecoinvent Version 3 (Weidema et al. 2013).

Denmark	Generation in 2012 PJ	Generation in 2020 PJ	Change in generation 2012-2020 PJ	Applied electricity mix in consequential modelling Switch 1	Applied electricity mix in attributional modelling Switch 2-4
Coal	62	23	0	0	0.501
Oil	18	1	0	0	0.032
Gas	30	4	0	0	0.206
Waste	2	0	0	0	0
Straw	0	1	0	0	0
Wind	17	70	34.8	0.81	0.209
Wood	0	6	2.6	0.06	0.052
Other RE*	1	0	5.7	0.13	0
Total	**130**	**105**	**43.1**	**1.00**	**1.00**

Table 3.3: Data for power generation in Sweden 2012, predictions for 2020, and the applied electricity mixes for the four switches. Data are obtained from the IEA database (2012), European Commission (2010c) and ecoinvent Version 3 (Weidema et al. 2013).

Sweden	Generation in 2012 TWh	Generation in 2020 TWh	Change in generation 2012-2020 TWh	Applied electricity mix in consequential modelling Switch 1	Applied electricity mix in attributional modelling Switch 2-4
Coal	1.3	1.34	0	0.004	0.008
Oil	0.6	0.67	0	0.002	0.006
Gas	0.9	0.93	0	0.003	0.012
Biomass	13.5	16.7	3.2	0.293	0.061
Nuclear	64.0	66.4	2.4	0.215	0.423
Hydro	79.1	68	-11.1	0	0.476
Wind	7.2	12.5	5.3	0.482	0.014
Geothermal	0	0	0	0	0
Solar	0	0.02	0	0	0
Marine	0	0	0	0	0
Total	**167**	**167**	**0**	**1.00**	**1.00**

Table 3.4: Data for power generation in United Kingdom 2012, predictions for 2020, and the applied electricity mixes for the four switches. Data are obtained from the IEA database (2012), European Commission (2010d) and ecoinvent Version 3 (Weidema et al. 2013).

United Kingdom	Generation in 2012 TWh	Generation in 2020 TWh	Change in generation 2012-2020 TWh	Applied electricity mix in consequential modelling Switch 1	Applied electricity mix in attributional modelling Switch 2-4
Coal	144	72.9	-71.27	0.000	0.323
Oil	3.1	2.8	-0.23	0.000	0.016
Gas	100	134.9	34.80	0.310	0.472
Biomass	12.9	26.0	13.08	0.116	0.007
Nuclear	70.4	26.2	-44.21	0.000	0.138
Hydro	8.3	6.3	-1.95	0.000	0.024
Wind	19.6	78.0	58.42	0.520	0.020
Geothermal	0.0	0.0	0.00	0.000	0
Solar	0.0	2.0	2.00	0.018	0
Marine	0.0	4.0	4.00	0.036	0
Total	**358.5**	**354**	**-4.49**	**1.00**	**1.00**

The GHG-emissions related to electricity in the inventoried countries are presented in Table 3.5.

Table 3.5: GHG-emissions related to electricity production and distribution in 2012.

Electricity GHG-emissions (kg CO_2-eq.)	Elec DE	Elec DK	Elec SE	Elec UK
Reference flow	1 kWh	1 kWh	1 kWh	1 kWh
Switch 1: ISO 14044/44				
Process data, ex infrastructure	0.262	0.0173	0.0783	0.183
Capital goods	0.0310	0.0314	0.0190	0.0210
Services	0.00195	0.00195	0.00195	0.00195
Switch 2: average/allocation				
Process data, ex infrastructure	0.654	0.501	0.0553	0.661
Capital goods	0.0110	0.0130	0.00730	0.0110
Services	0.00195	0.00195	0.00195	0.00195
Switch 3: PAS2050				
Process data, ex infrastructure	0.654	0.501	0.0553	0.661
Capital goods	0.0110	0.0130	0.00730	0.0110
Services	0.00195	0.00195	0.00195	0.00195
Switch 4: IDF				
Process data, ex infrastructure	0.654	0.501	0.0553	0.661
Capital goods	0.0110	0.0130	0.00730	0.0110
Services	0.00195	0.00195	0.00195	0.00195

3.4 Fertilisers and other chemicals

One change is introduced in the nitric acid production (‘Nitric acid, 50% in H_2O, at plant/RER U’ in Ecoinvent Version 2 (Frischknecht et al. 2005), what influences the emission from ammonium nitrate (AN) and calcium ammonium nitrate (CAN). According to European Commission (2007, Table III), the N_2O emission for existing plants applying best available technology (BAT) is 0.00185 kg N_2O/kg HNO_3, while in 2005-data this number was higher: 0.00839 kg N_2O/kg HNO_3. As a consequence of this improvement, the emissions from production of AN decrease from 7.96 to 4.09 kg CO_2 eq/kg N and from CAN from 8.06 to 4.19 kg CO_2 eq/kg N.

3.5 Fuels and burning of fuels

These data have been collected for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

3.6 Transport

These data have been collected for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

3.7 Capital goods and services in cattle and crop farms

These data have been modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

3.8 Capital goods and services in the food industry activities

These data have been modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

3.9 Indirect land use changes (iLUC)

According to IPCC (2014), 11% of global GHG emissions relates to land use changes. Land use change emissions arise when one land cover is transformed to another land cover with a lower carbon stock. Assuming that it is the demand for land that drives land use changes, the exclusion of these emissions from an LCA may lead to a significant underestimation of GHG emissions from products that are associated with the use land – such as food, biofuels, and bio-based materials. The contribution from land use changes is included in the results in the current study by applying two different models:

- A model for indirect land use changes: the 2.-0 LCA iLUC model version 4.1 (Schmidt et al. 2015; Schmidt and Muñoz 2014, sections 3.5 and 5.4).
- PAS2050 (2008, 2011)

The 2.-0 LCA iLUC model is applied for two of the model switches for which results are calculated in the current study:

- ISO14040/44 – consequential modelling, and
- Average/allocation – attributional modelling

For the two other model switches, the PAS2050 approach has been used, namely the model switches:

- PAS2050, and
- IDF Guideline

4 The cattle system

This chapter documents the inventory of the cattle system, i.e. all the inputs and outputs related to the milk-producing animals including their offspring. The first section in this chapter (section 4.1) presents an overview of the cattle systems in the inventoried countries: Germany, Denmark, Sweden, United Kingdom and Brazil. This includes data and assumptions about stocks and flows of animals of the baseline year 2012. In the next section (section 4.2), the feed requirements and the composition of the feed are inventoried. In section 4.3, other inputs and materials to treatment in the cattle system are inventoried. This includes the use of energy, transport, capital goods and services. Materials for treatment include manure and animals to destruction. Section 4.4 presents the inventory of emissions from the cattle systems. In sections 4.5 and 4.6 a summary of the inventory and the relevant parameters relating to switch between modelling assumptions (switches) are presented respectively.

4.1 Overview of the cattle system

Cattle turnover, stock and related parameters: Germany

The animal turnover in the German milk and beef systems is presented in Figure 4.1 and Figure 4.2 and the parameters we use are summarised in Table 4.1. For more details on the included activities see Schmidt and Dalgaard (2012a, Table 6.1).

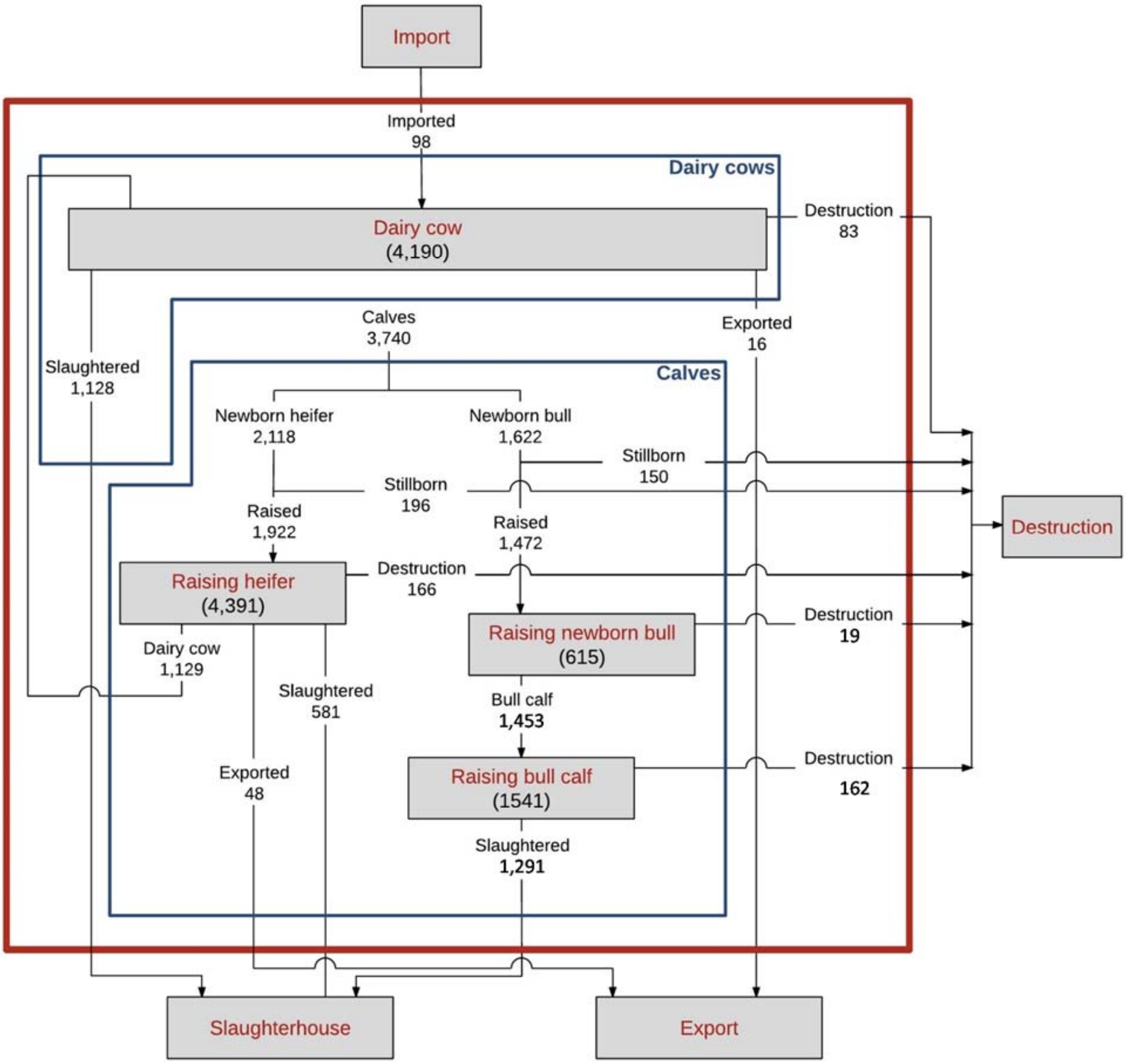

Figure 4.1: Milk system turnover in Germany 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

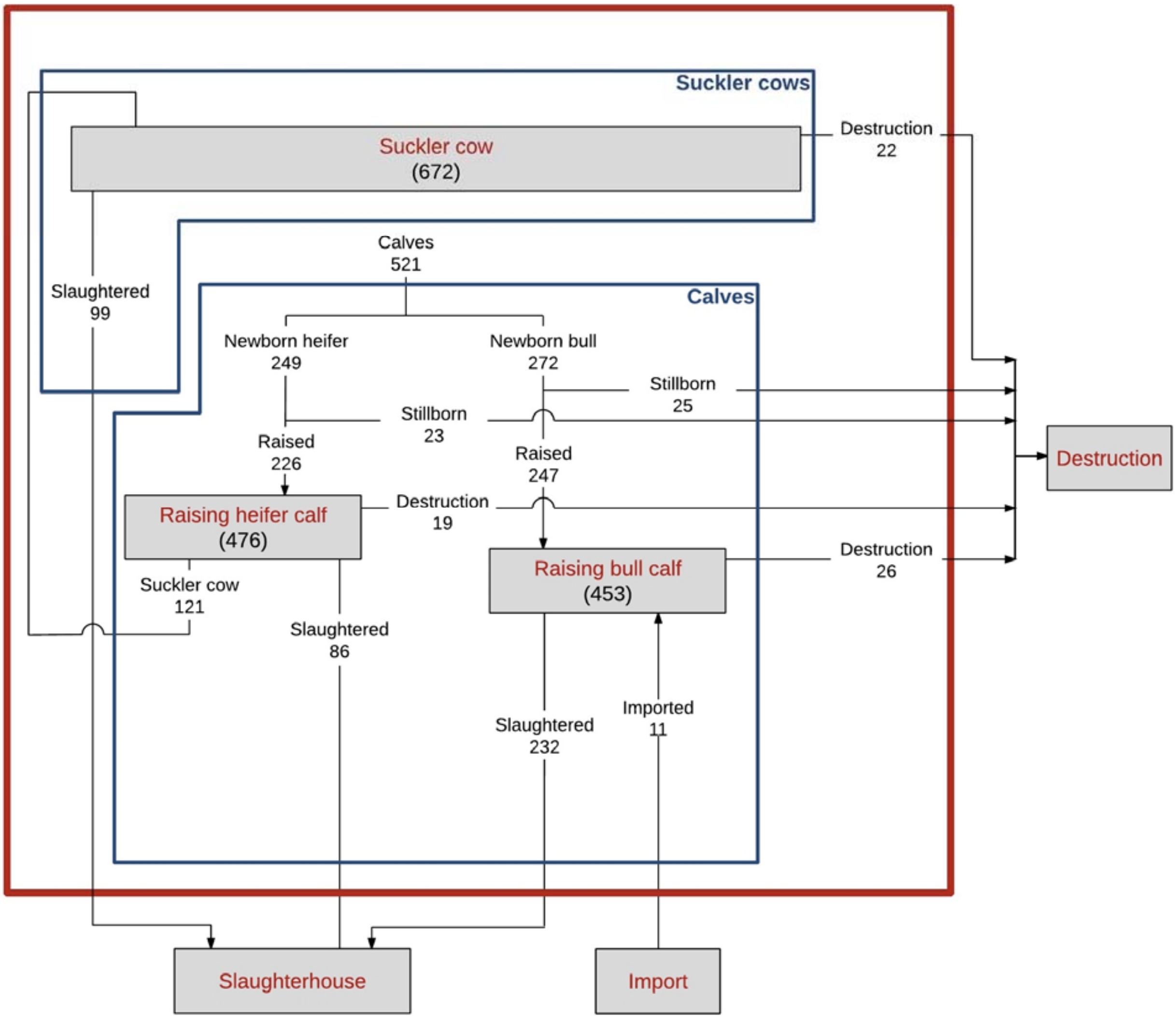

Figure 4.2: Beef system turnover in Germany 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

The cattle turnover for both dairy and beef systems in Germany is built around the data available in the National German Statistics (Statistisches Bundesamt 2014). All stock sizes are obtained directly from Statistisches Bundesamt (2013a, Section 2.1.1.) with the exception for 'newborn bulls' in dairy system, which do not fit any of reported age categories of cattle. Given that the time which bulls spent in this activity is not clearly defined, we calculate it based on the change in weight (from Haenel et al. 2014) and weight gain per day, which we assumed is the same like for Denmark in 2005, 0.042 kg/day (Dalgaard and Schmidt 2012a). As a result, newborn bulls spent 152 days in the activity.

The distribution of animals between the dairy and beef systems as well as between male and female cattle (in case of calves below 8 months) is based on the statistics on the population sizes of different dairy, dual-purpose and beef breeds in Statistisches Bundesamt (2013a, Section 2.1.3.). According to these statistics, there is a majority of female animals, and we subsequent calculate that there should be given birth to more female than male calves. In reality, the distribution is close to 50% / 50%, and the difference we see is probably because more male calves are killed and sent to destruction. The discrepancy in sex distribution does not affect the model results.

It was chosen to establish the balance as a steady state flow of animals, i.e. there are no changes in stock of animals during the accounting year. Since the changes in stocks are a part of the actual balance, we chose to adjust the number of slaughtered animals to be able to arrive at zero stock changes. This resulted in a reduction of the number of slaughtered animals by 6.40% from 3,654,794 (Statistisches Bundesamt 2013b) to 3,420,850. Number of slaughtered heads for each cattle category (heifers, young bulls etc.) is also obtained from Statistisches Bundesamt (2013b).

The numbers of heifers becoming dairy and suckler cows are adjusted to balance the flow and result in replacement rates of 28.3% and 16.4%, respectively.

According to ADR (2013), approximately 83,069 dairy cows left the herd due to “other diseases” and we assume they are not suitable for slaughter and therefore sent to destruction. Since no national data about the stillborn heifers and bulls are available, the values reported for two German districts: 9.3% in Thuringia (Hoedemaker et al. 2010) and 9.20% in Bayern (LFL 2005) are used as a reference. The average of 9.25% mortality is assumed for newborn heifers and bulls both in milk and beef system. All the remaining flows of animals for destruction are calculated using the mortalities reported in Pannwitz (2015) and the age of given cattle category from our study.

Information about the export of German dairy cattle is provided by ADR (2013). The aggregated number of exported female cattle (63,000 heads) is distributed between heifers and cows according to the proportion from Denmark in 2005: 3 exported heifers per one exported dairy cow (Dalgaard and Schmidt 2012a).

Weights of cattle from Haenel et al. (2014) are adopted in this study. The weight of fallen and exported animals is calculated as an average of the weights when entering and leaving each activity. The weight of slaughtered cattle is extracted from Statistisches Bundesamt (2013b), using 55% factor to calculate from carcass weight to live weight. The default value for dressing percentage for cattle is 60% according to FAO (1991). However, data on dressing percentages for German cattle are apparently lower (49-56%) as published by Dämmgen et al. (2010). Thus 55% is used in the current study for calculating the ratio between live weight and carcass weight in Germany. Since Statistisches Bundesamt (2013b) does not distinguish between dairy and beef cattle the same, average weights are applied in both milk and beef system. The weight gain per day is calculated by dividing the difference between the start and end weight with the time spent in given activity. Due to lack of data, for raising newborn bulls the Danish weight gain (0.42) is applied (Dalgaard and Schmidt 2012a).

Time spent in the activity for the cattle categories besides ‘raising newborn bull’ is calculated based on the stock size and the inflow. In case of ‘raising newborn bulls’ the time is calculated from the weight gain per day and the difference between the start and end weight. By summing up days that dairy bulls spent as newborn (152) and calves (436) we obtain the average age of dairy bull of 588 days. According to LKV (2012), the average age of bulls at slaughter in Bavaria was 579 days, what shows that our assumption is correct.

The amount of produced milk was taken directly from statistical data. Since the stock change in dairy cows was very small in 2012, no corrections as for the slaughtered animals were made for the milk. The amount of produced meat (carcass weight) is calculated as animal weights (Statistisches Bundesamt 2013b) multiplied by the number of different animal categories sent to slaughter. After converting from carcass to live weight implied amount of cattle meat is 2,008 million tonne. This should be compared to 2,084 million tonne as of official statistics (Statistisches Bundesamt 2014). The implied amount is 3.86% less than the official amount, and it is related to the reduced number of animals sent to slaughter.

Table 4.1: Parameters used for accounting for flows and stocks of animals. Germany.

Germany	Unit	Milk system				Beef system		
Parameters		Dairy cow	Raising heifer calf	Raising newborn bull	Raising bull calf	Suckler cow	Raising heifer calf	Raising bull
Stock (annual average)	heads	4,190,48	4,390,62	286,857	2,037,706	672,266	476,117	452,715
Weight gain	kg day^{-1} head^{-1}	0.0395	0.547	0.888	0.934	0.028	0.581	0.840
Period in activity	days	1,290	912	72	576	2,232	837	713
Inflow								
Cow or calf	heads	1,129	1,922,51	1,472,385	1,453,166	25,000	226,256	247,220
Imported	heads	97,919						
Outflows								
Newborn heifers	heads	2,118,47				249,318		
Newborn bulls	heads	1,622,46				272,419		
Stillborn heifers	heads	195,959				23,062		
Stillborn bulls	heads	150,078				25,199		
Fallen	heads	83,069	165,607	19,219	162,144	22,424	18,730	26,251
Slaughtered	heads	1,127,95	580,807		1,291,020	98,749	86,353	231,850
Exported	heads	15,750	47,250					
Weights								
When entering activity	kg head^{-1}	499	36	36	100	487	48	51
When leaving activity	kg head^{-1}	550	535	100	638	550	535	649
Stillborn	kg head^{-1}	36				48		
Fallen animal	kg head^{-1}	525	286	68	369	518	292	350
Exported/imported animal	kg head^{-1}	525	286	68	369	518		
Slaughtered animal	kg head^{-1}	550	535	100	638	550	535	649

*Period from an animal enters an activity to it leaves for slaughter or it goes to another activity (e.g. when a heifer becomes a dairy cow).

Cattle turnover, stock and related parameters: Denmark

The animal turnover in the Danish milk and beef systems is presented in Figure 4.3 and Figure 4.4 and the parameters we use are summarised in Table 4.2. For more details on the included activities see Schmidt and Dalgaard (2012, Table 6.1).

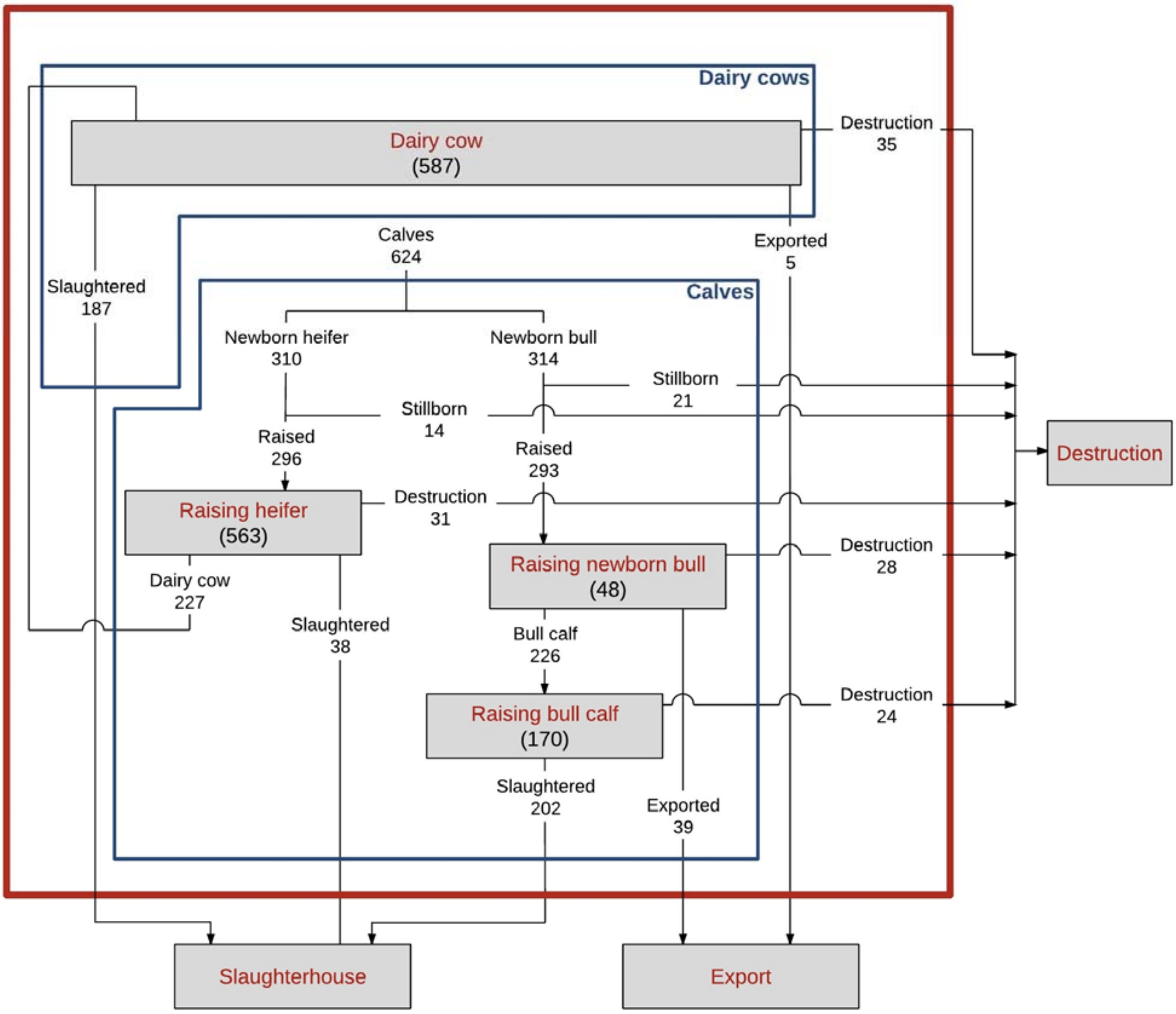

Figure 4.3: Milk system turnover in Denmark 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

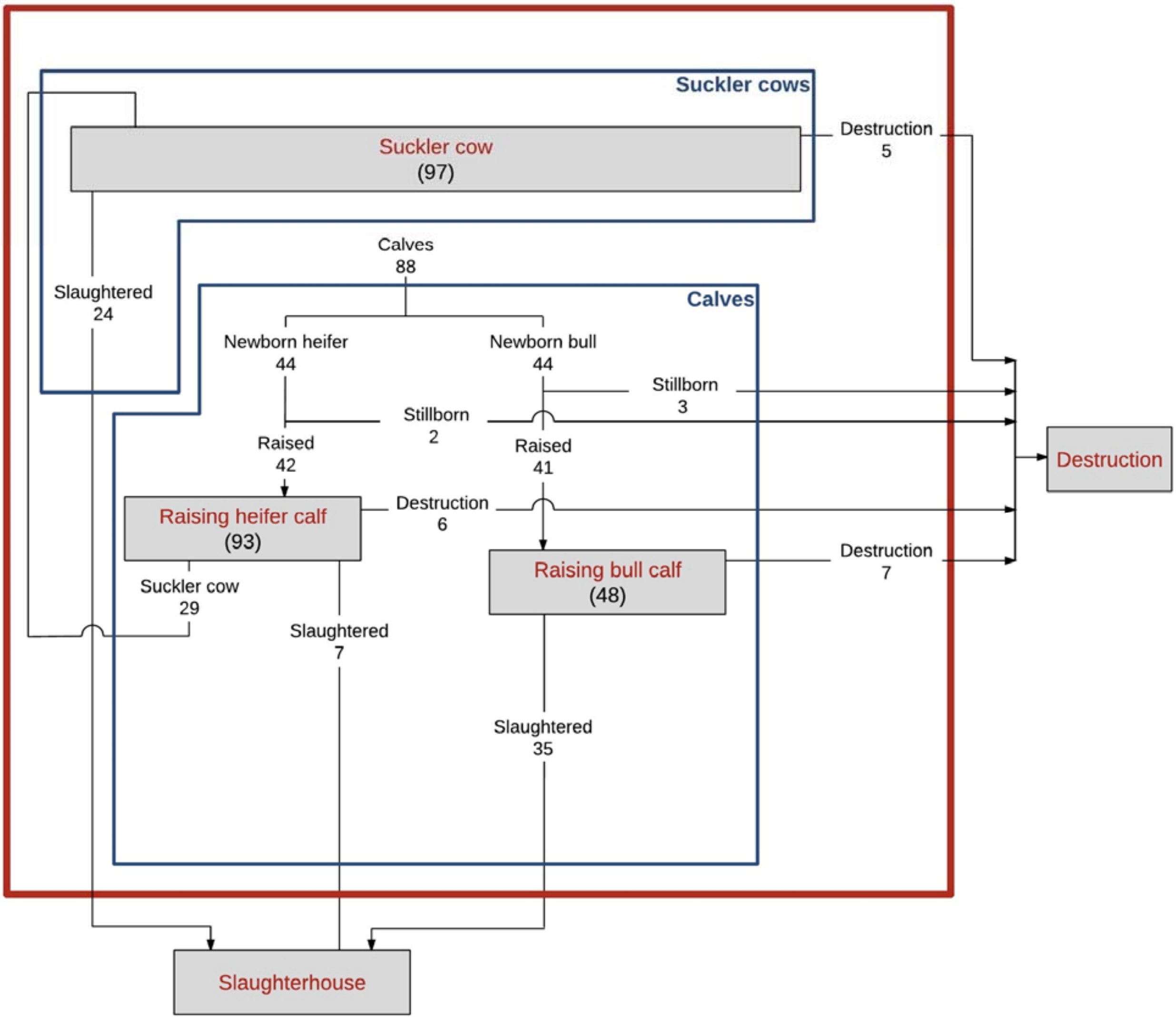

Figure 4.4: Beef system turnover in Denmark 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

As the starting point, sizes of dairy and suckler cow stocks are obtained from Statistics Denmark (2014). To estimate stocks of heifers the total number of heifers available in Statistics Denmark (2014) is distributed between milk and beef system based on the proportion between dairy and suckler cows (85.8% to 14.2%). Stocks of dairy bulls (newborn and bull calves) are estimated using their inflows and times spent in the activities due to differences in the definition of young bulls in the literature. The stock of beef bulls is calculated as a difference between the total amounts of male cattle (265,741 heads) reported in Statistics Denmark (2014) and obtained stocks of dairy bulls (48,124 and 170,063 heads).

The number of newborn heifers and bulls can be found in Seges (2015a), which reports the total number of dairy cattle births with gender distribution. The births with unknown gender (0.53%) are distributed equally between heifers and bulls. Newborn heifers and bulls in the beef system are calculated 'backwards': from the stock sizes and days spent in respective activities we obtain their flows. Incorporating the mortalities lets us estimate the initial amount of newborns. Calving rates obtained with these numbers (106% for milk and 90.5% for beef system) are almost similar to the ones from 2005 (105% and 95.4%) published in Dalgaard and Schmidt (2012a).

As mentioned above, 85.8% of cows are dairy but in case of pregnant heifers we expect this percentage to be higher because in dairy system pregnancies are more frequent in order to maintain high milk production. Therefore, we assume that 89% of the total number of pregnant heifers (Statistics Denmark 2014) belongs to the milk system and remaining 11% to beef system. Obtained values are then converted from stocks of pregnant heifers into flows (inputs into the stocks of dairy and beef cows) by using the length of cattle pregnancy, here assumed to be 281 days (Dansk Landbrugsrådgivning 2007). Finally, to balance the animal flow, the number of heifers, which become dairy cows, is increased by 10,000 heads. With these calculations we reach reasonable replacement rates: 38.6% for milk system and 30.1% for beef system.

Average mortality of dairy cows in 2012 equaled 5.10% (Seges 2015b) and in this report is increased to 5.94% to maintain the flow at steady state. For suckler cows 5.10% mortality is assumed, while for newborn dairy heifers and bulls it is based on Cattle Database (Kvægdatabasen) and is, respectively, 4.50% and 6.70% (Seges 2015c). These rates are also used in the beef system. Seges (2015c) provides mortalities of dairy heifers and bulls until 30 and 180 days old. Recalculating these values taking in consideration how much time different cattle categories spent in the activities let to average annual mortalities. With small adjustments to assure the balance in animal flows they are used in milk and beef systems.

Number of slaughtered dairy cows is estimated from the number of all slaughtered cows by multiplying it with 85.8%, the share of dairy cows in the total number of cows in Denmark (Statistics Denmark 2014). This gives a value of 181,206 heads, but in order to maintain the steady state both in dairy and suckler cow flows we 'transfer' 5,670 slaughtered cows from beef to milk system and finally obtain 186,876 and 24,328 heads, respectively. Data regarding heifers are extracted from Statistics Denmark (2014), assuming that 85.8% of slaughtered heifers belong to the milk system. The number of slaughtered bulls from milk system is estimated as difference between the input to the activity and outputs other than slaughter: destruction and export. By subtracting obtained number from the total number of male cattle slaughtered in 2012 (Danish Agriculture and Food Council 2013) we obtain the amount of slaughtered beef bulls. Finally, we raise the slaughtered beef bulls by 4,890 heads to balance the flow.

It is assumed that the exported adult cattle (Statistics Denmark 2014) refer entirely to the dairy cows. In Andersen and Hansen (2013) it was expected that 37,400 young bulls from dairy farms would be exported in 2012. Therefore, the assumption that all of the exported 38,300 calves (Statistics Denmark 2014) are bulls in milk system seems valid.

The weights of Danish cattle are based on Lund and Aaes (2012) as presented by Bligaard (2013a). The calculations use distribution between Jersey and large breeds (12.5 % to 87.5%), according to the proportion of cattle from these breeds born in 2012 in Denmark (Seges 2015a). The weight of fallen and exported animals is calculated as an average of the weights when entering and leaving the activity. The weight of slaughter cattle is assumed to equal the weight when leaving the activity. The slaughter weight of young bulls is taken from Mikkelsen et al. (2014). Based on the data above, the slaughter weight of heifers is 515 kg. The weight of a newborn heifer is 38 kg. Hence, the average weight is 276 kg. However, based on data collected by Arla Foods in 2011-2013 from 632 farms in Denmark, the average weight of heifers is 309 kg. To obtain this weight, the slaughter weight of heifers has been changed to 580 kg. In the beef system, the same weights as in 2005 are applied (Dalgaard and Schmidt 2012a).

Weight gain and period spent in the activity are calculated based on the earlier estimated parameters. The only exception is time that bulls from the milk system spend in the two activities. To calculate the stock sizes it is assumed that newborn bulls spend 2 months in the first activity and are slaughtered at the age of 11 months (Seges 2015a).

Table 4.2: Parameters used for accounting for flows and stocks of animals. Denmark.

Denmark	Unit	Milk system				Beef system		
Parameters		Dairy cow	Raising heifer calf	Raising newborn bull	Raising bull calf	Suckler cow	Raising heifer calf	Raising bull
Stock (annual average)	heads	587,189	563,441	48,124	170,063	97,193	93,262	47,553
Weight gain	kg day^{-1} head^{-1}	0.035	0.699	0.350	1.19	0.091	0.502	0.953
Period in activity*	days	1,023	775	66	307	1,323	955	501
Inflow								
Cow or calf	heads	227,000	296,263	292,756	226,063	25,000	41,717	41,326
Outflows								
Newborn heifers	heads	310,223				43,682		
Newborn bulls	heads	313,779				44,294		
Stillborn heifers	heads	13,960				1,966		
Stillborn bulls	heads	21,023				2,968		
Fallen	heads	34,861	30,989	28,393	23,979	4,957	6,081	6,705
Slaughtered	heads	186,876	38,352		202,084	24,328	6,348	34,625
Exported	heads	5,200		38,300				
Weights								
When entering activity	kg head^{-1}	542	38	38	61	480	40	42
When leaving activity	kg head^{-1}	577	580	61	426	600	520	520
Stillborn	kg head^{-1}	38				40		
Fallen animal	kg head^{-1}	560	309	50	244	540	280	281
Exported animal	kg head^{-1}	560	309	50	244	540	280	281
Slaughtered animal	kg head^{-1}	577	580		426	600	520	520

*Period from an animal enters an activity to it leaves for slaughter or it goes to another activity (e.g. when a heifer becomes a dairy cow).

Cattle turnover, stock and related parameters: Sweden

The animal turnover in the Swedish milk and beef systems is presented in Figure 4.5 and Figure 4.6 and the parameters we use are summarised in Table 4.3. For more details on the included activities see Schmidt and Dalgaard (2012, Table 6.1).

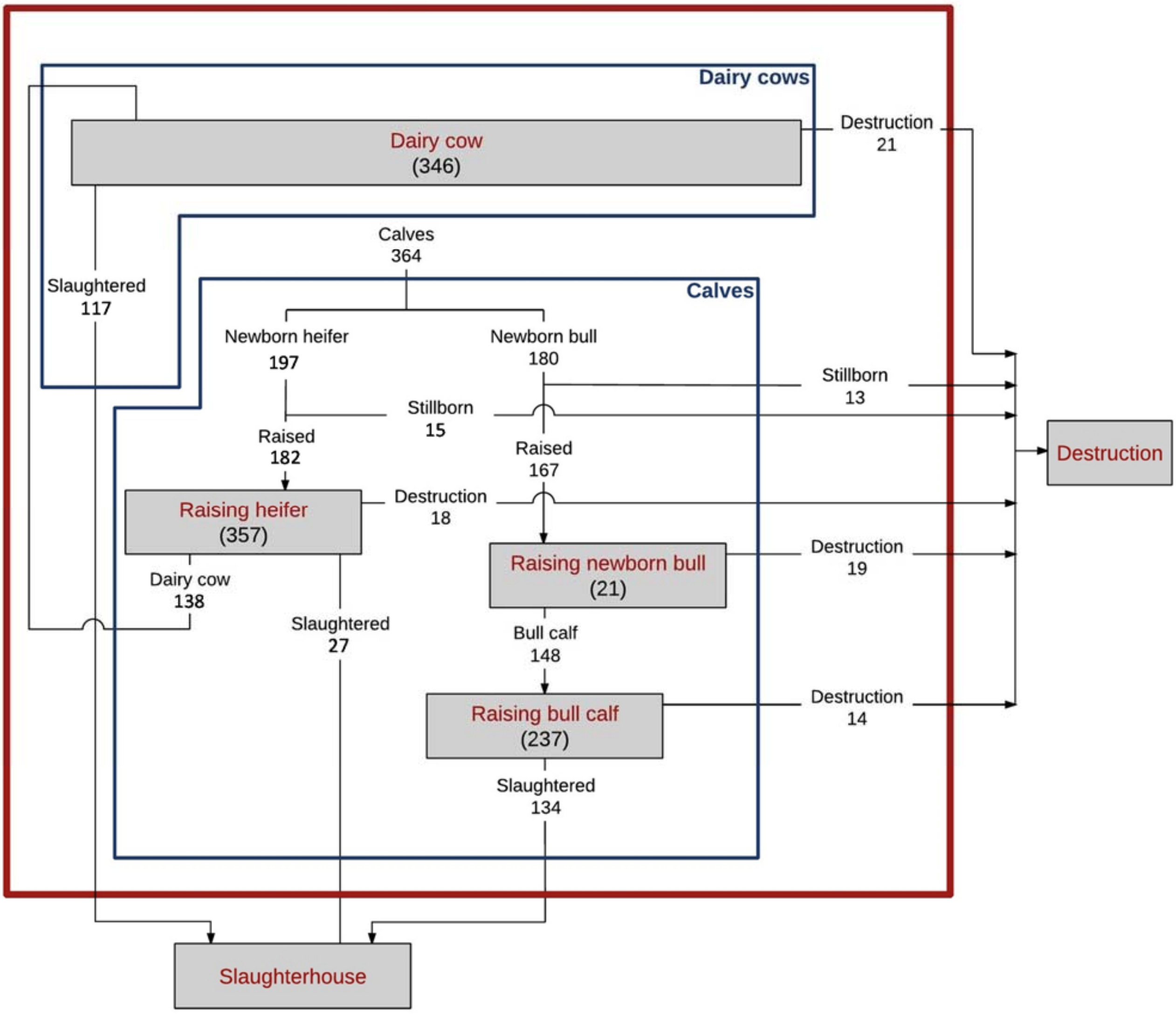

Figure 4.5: Milk system turnover in Sweden 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

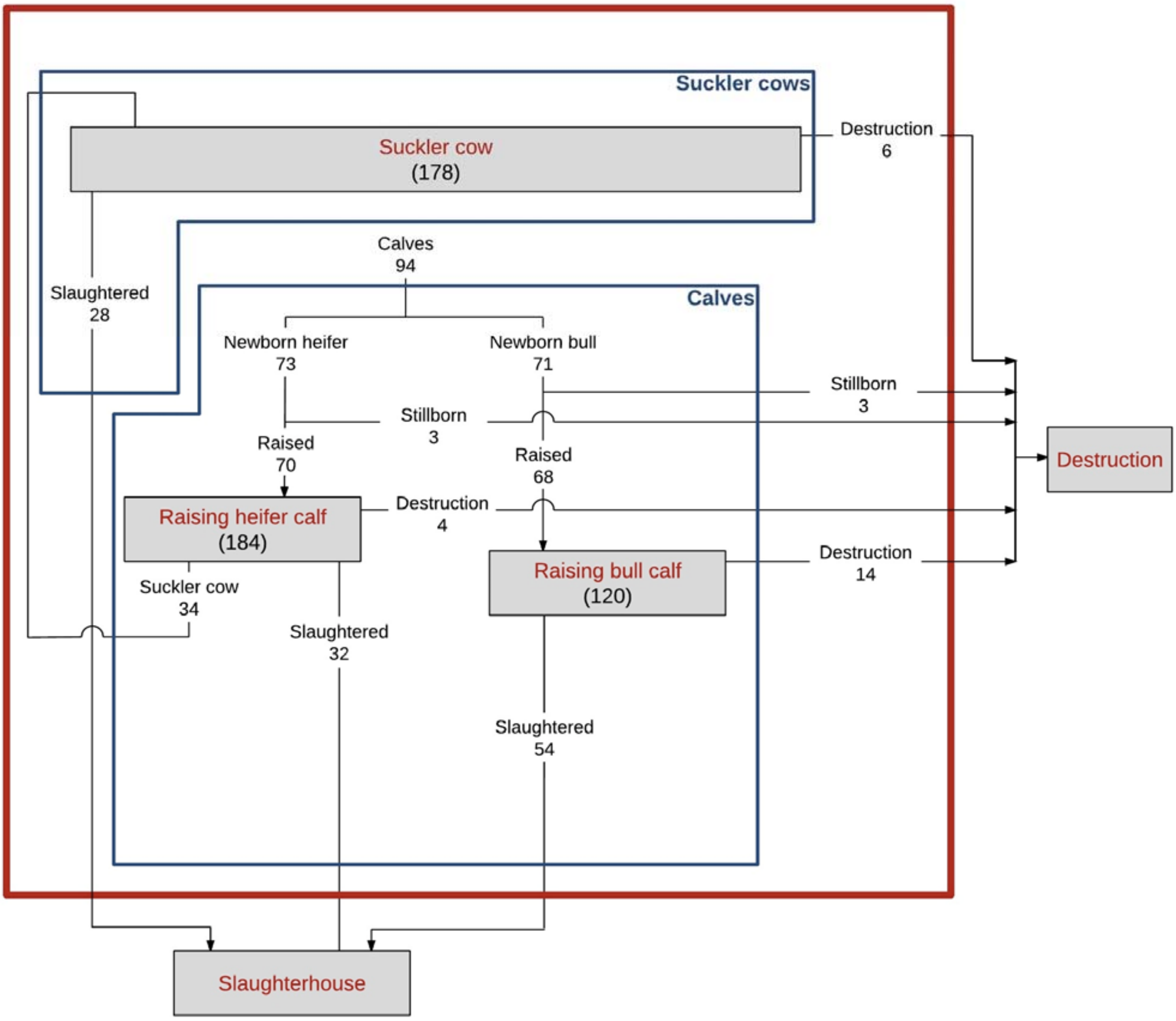

Figure 4.6: Beef system turnover in Sweden 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

To establish the cattle turnover in Sweden we use data available in Swedish Statistics (SCB 2015). Firstly, we extract stock sizes of dairy and suckler cows, directly provided by the source. Besides cows, SCB (2015) reports three other groups of female cattle: 'Female calves', 'Heifers (1-2 years)' and 'Heifers (> 2 years)'. In our study they all belong to the stock of heifers. To distribute them between milk and beef systems, we maintain the same proportion as SCB (2015) provides for cows (66.0% dairy and 34.0% beef). This results in 357,201 heads of dairy heifers and 184,320 heads of beef heifers. Similar method is used to estimate the stocks of bulls. We also sum up the numbers of 'Male calves' and 'Total bulls and steers' but here the distribution is based on the proportion between dairy and beef bulls in Sweden 2005 (Dalgaard and Schmidt 2012a). Additionally, dairy bulls are divided into two activities: 'Raising newborn bulls' and 'Raising bull calves'. We assume that time spent in the first activity is 47 days, the same as in Sweden 2005 (Dalgaard and Schmidt 2012a) and we use this value to calculate the size of stock. To obtain the number of 'Bull calves', the stock of 'Newborn bulls' is then subtracted from the total number of bulls from dairy farms.

The numbers of heifers becoming dairy and suckler cows are adjusted to balance the flow and result in replacement rates of 39.9% and 18.3%, respectively. Values are comparable to the ones obtained in 2005: 37.9% and 28.9% (Dalgaard and Schmidt 2012a).

The initial information about slaughtered cattle is obtained from Jordbruksverket (2014). Since the source does not distinguish between milk and beef systems, we need to estimate the distribution. Firstly, we assume that for both systems the percentages of slaughtered cows, heifers and bulls did not change between 2005 and 2012. We use these rates to calculate the number of slaughtered cattle in each category. Secondly, obtained numbers are adjusted (keeping the proportion between dairy and beef) so that the sum of slaughtered dairy and suckler cows matches the total number of slaughtered cows (Jordbruksverket 2014). The same adjustment is done for heifers and bulls. In order to maintain the steady flow of animals, the number of all slaughtered cattle is afterwards decreased by 2.64% and final, minor redistribution between cattle categories is done.

In order to respect the number of slaughtered animals, we had to adjust the total cattle slaughtered in Sweden in 2012 as of Jordbruksverket (2014).The consequence of modifying the slaughter statistics is that model covers 97.4% of total cattle slaughtered and 97.5% of total carcass obtained in 2012, according to Jordbruksverket (2014).

Mortalities of all cattle categories, both in milk and beef systems, are taken from Dalgaard and Schmidt 2012a). Import and export are neglected based on the fact that FAOSTAT reports no imported and only 440 exported animals in Sweden 2011 (no newer data are available). Time spent in the activity is calculated based on inflows and stock sizes for all the categories besides newborn bulls, were the time is assumed to equal 2005 data (Dalgaard and Schmidt 2012a).

Table 4.3: Parameters used for accounting for flows and stocks of animals. Sweden.

Sweden	Unit	Milk system				Beef system		
Parameters		Dairy cow	Raising heifer calf	Raising newborn bull	Raising bull calf	Suckler cow	Raising heifer calf	Raising bull
Stock (annual average)	heads	345,527	357,201	21,441	237,129	178,296	184,320	119,670
Weight gain	kg day^{-1} head^{-1}	0.053	0.546	0.830	0.703	0.082	0.424	0.623
Period in activity*	days	989	792	47	646	2,199	1,019	799
Inflow								
Cow or calf	heads	138,000	182,442	166,509	148,008	25,000	69,781	68,341
Outflows								
Newborn heifers	heads	197,000				73,023		
Newborn bulls	heads	179,951				71,248		
Stillborn heifers	heads	14,558				3,242		
Stillborn bulls	heads	13,442				2,907		
Fallen	heads	21,077	17,816	18,501	14,038	6,044	3,752	13,707
Slaughtered	heads	116,948	26,600		133,970	26,576	33,409	54,716
Weights								
When entering activity	kg head^{-1}	432	40	40	79	432	40	40
When leaving activity	kg head^{-1}	485	472	79	533	612	472	538
Stillborn	kg head^{-1}	40				40		
Fallen animal	kg head^{-1}	459	256	60	306	522	256	289
Slaughtered animal	kg head^{-1}	459	256	60	306	522	256	289

*Period from an animal enters an activity to it leaves for slaughter or it goes to another activity (e.g. when a heifer becomes a dairy cow).

Cattle turnover, stock and related parameters: United Kingdom

The animal turnover in the British milk and beef systems is presented in Figure 4.7 and Figure 4.8 and the parameters we use are summarised in Table 4.4. For more details on the included activities see Schmidt and Dalgaard (2012, Table 6.1).

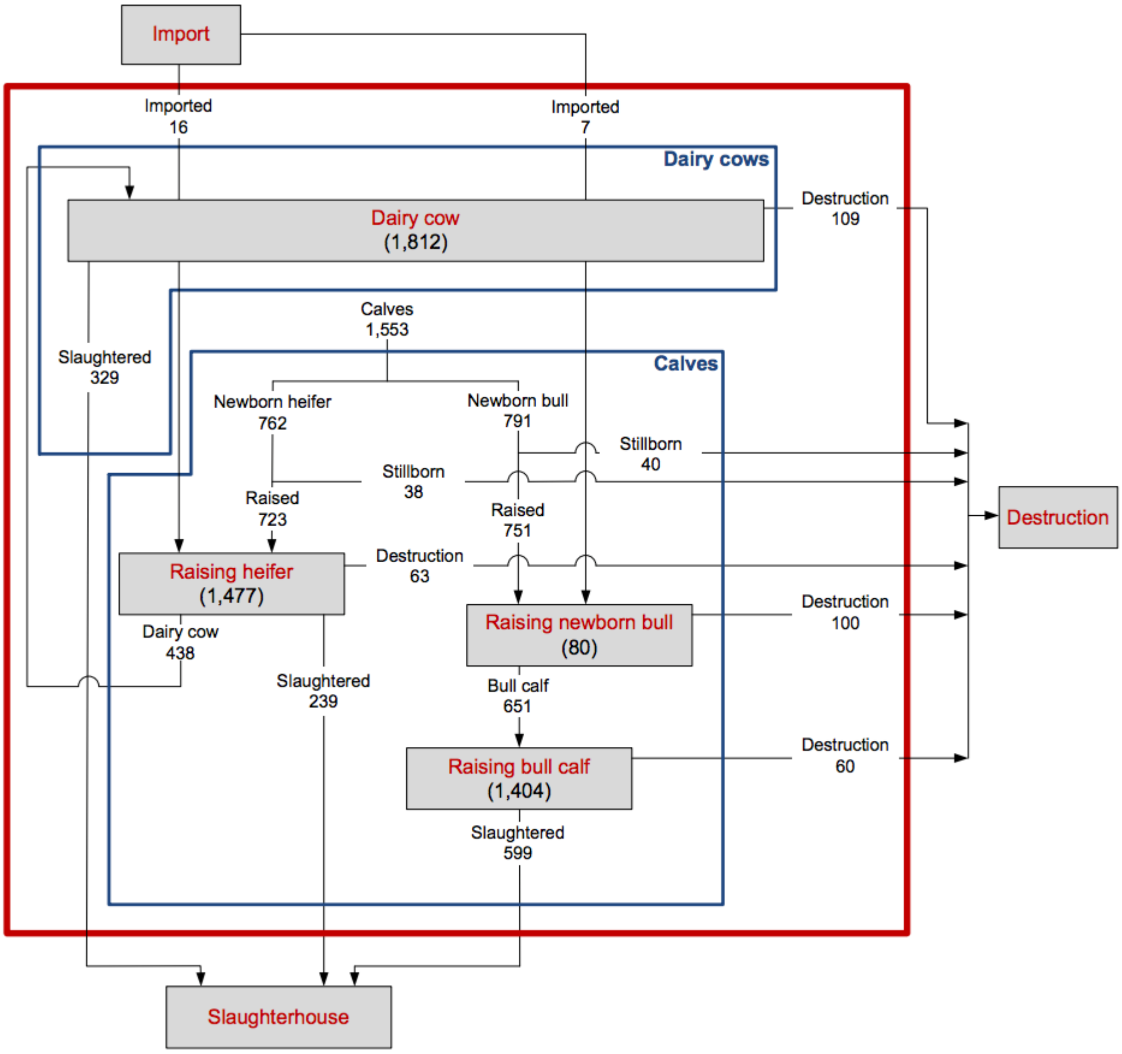

Figure 4.7: Milk system turnover in United Kingdom 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

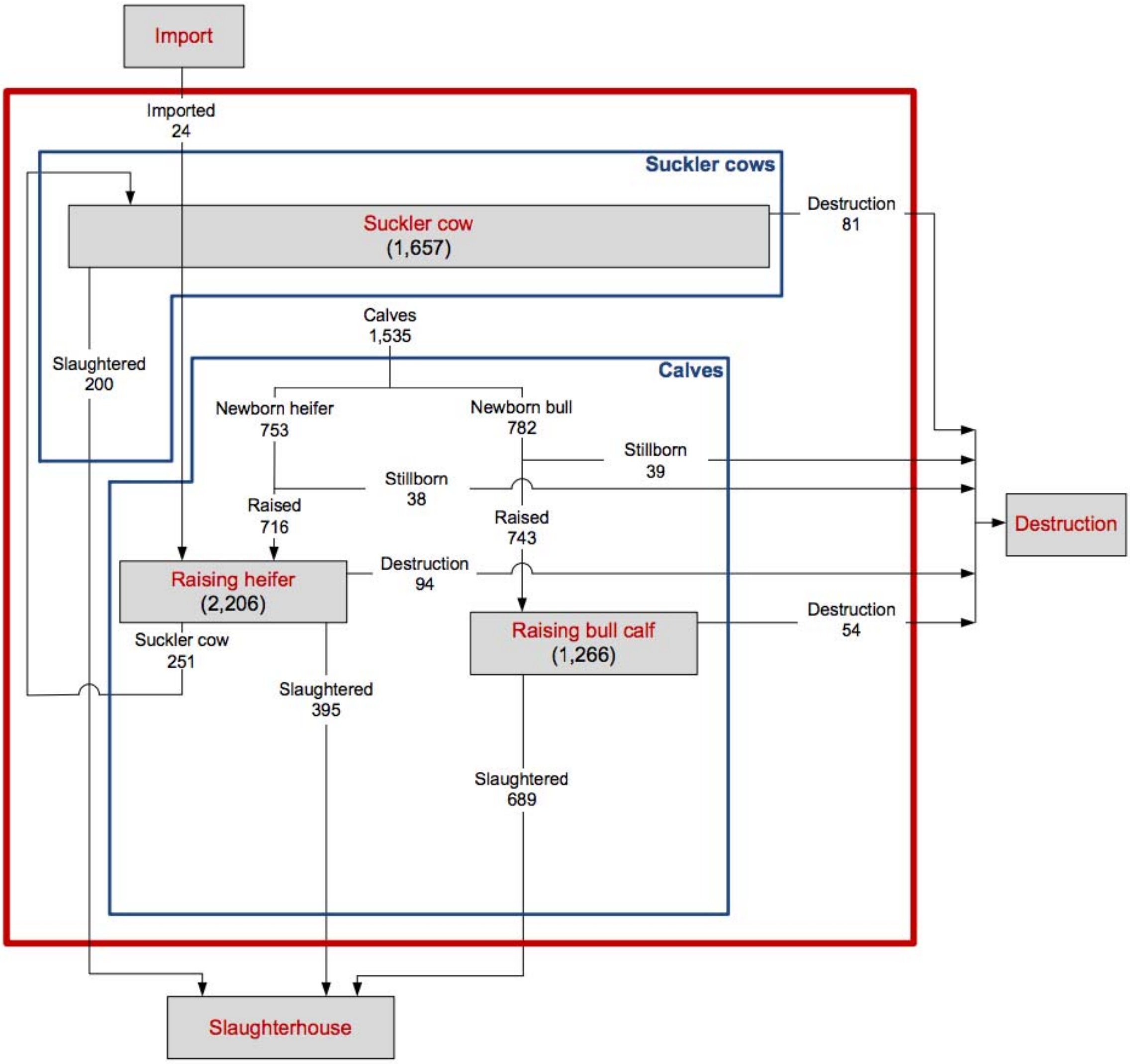

Figure 4.8: Beef system turnover in United Kingdom 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

The animal turnover for United Kingdom is modelled based on British statistics (Defra 2012), where data regarding cattle population take into consideration animal's age, gender and whether the animal is kept for milk or beef production. Stock sizes of dairy and suckler cows are extracted directly from Defra (2012). The stocks of heifers (both milk and beef) are calculated as sum of the female cattle from all the age groups besides '2 years or more (breeding herd)', which represents cows. The stock of young dairy bulls is calculated from the input and time spent in the activity, which we assume equals 39 days reported for United Kingdom in 1990 (De Rosa et al. 2013). Subtracting the stock of young bulls from the total number of bulls belonging to dairy herds we obtain the stock size of the remaining, older bulls. Bulls from the beef systems are simply the sum of all beef males reported in Defra (2012).

Since the number of newborn cattle was difficult to establish based on data from Defra (2012) we use the calving intervals from CHAWG (2014) and multiply them with the number of dairy and suckler cows (Defra 2012). Distribution between males and females is assumed to be, respectively, 49.1% to 50.9% (CHAWG 2014, Table 14). In both milk and beef system the number of pregnant heifers, which become cows, is calculated based on other inputs and outputs to balance the flow of heifers. In the end we obtain a steady flow and replacement rates of 24.2% and 15.1%, respectively.

Mortality rates in the dairy herd are based on values used in De Rosa et al. (2013). One additional number is added: bull calves killed shortly after birth. Since there is no statistical record of these deaths, based on CiWF (2015) and McDermott (2012), we estimate that in 2012 this number was 100,000 heads. Since the model used for United Kingdom 1990 does not include beef system, we adapt the mortalities from dairy cattle also in case of beef cattle. The only exception is the mortality of suckler cows, which is 4.88%, according to CHAWG (2014).

Statistics about slaughtered animals are delivered from the file cited in the National Inventory Report (Webb et al. 2014a, annotation on page 662). The source does not specify whether the slaughtered cattle belong to dairy or beef herds, therefore some assumption are made. Based on the slaughter rates for previous years and other studied countries (Dalgaard and Schmidt 2012a; De Rosa et al. 2013) we make a preliminary distribution of heifers and cows between two types of herds. Afterwards, these values are introduced to flow and we redistribute the slaughtered heads in order to maintain the steady flow of cattle. In case of suckler cows we decide to make an exception and slaughter 30,000 heads more than it is needed to keep the stock change at zero. Our motive is lowering the time that these animals spent in the activity; otherwise the suckler cows would get too old before slaughter.

Due to less complicated structure of bulls' population, simpler approach can be used to estimate number of slaughtered heads. Slaughtered beef bulls are calculated as a difference between inputs and outputs to the 'Raising bull' activity so that the flow is balanced. Later, by subtracting this value from the total number of slaughtered male cattle (Webb et al. 2014a, annotation on page 662) we obtain the slaughtered dairy bulls. What is important, we assume that the category called 'Calves' consists only of male cattle.

Introduced changes result in decreased number of slaughter cattle but allow us to maintain the steady flow of animals. Overall, comparing to statistical data (Webb et al. 2014a), the model covers 85.1% of slaughtered cows, 88.6% of heifers and 92.6% of bulls.

According to FAOSTAT (2014), the export of cattle from United Kingdom was minor in 2011 (no newer data available) and is, therefore, neglected in this report. Out of 47,186 imported animals 40,070 were imported for breeding and 7,116 for slaughter (CHAWG 2014). We assume that cattle imported for breeding are dairy and beef heifers, distributed proportionally to the stock sizes, and cattle imported for slaughter are young dairy bulls.

The weights of newborn cattle are adapted from De Rosa et al. (2013) and we assume that they are the same for calves in milk and beef system. The weight of fallen and exported animals is calculated as an average of the weights when entering and leaving the activity. We use the average slaughter weights of cows and heifers (Webb et al. 2014a, annotation on page 662) for both the dairy and beef cattle. The slaughter weight of bulls is calculated as weighted average of calves, steers, young and adult bulls and results in 723 kg.

Weight gain and period spent in the activity are calculated based on the earlier estimated parameters. The only exception is that the time of 'raising newborn bull' is not calculated but assumed to equal 39 days like in De Rosa et al. (2013).

Table 4.4: Parameters used for accounting for flows and stocks of animals. United Kingdom.

United Kingdom	Unit	Milk system				Beef system		
Parameters		Dairy cow	Raising heifer calf	Raising newborn bull	Raising bull calf	Suckler cow	Raising heifer calf	Raising bull
Stock (annual average)	heads	1,811,646	1,477,000	80,257	1,403,917	1,657,244	2,206,000	1,265,825
Weight gain	kg day^{-1} head^{-1}	0.008	0.858	0.564	0.843	0.005	0.574	1.09
Period in activity*	days	1,510	729	39	778	2,155	1,089	622
Inflow								
Cow or calf	heads	438,000	723,496	751,125	651,125	25,000	715,587	742,914
Imported	heads		16,068	7,116			24,001	
Outflows								
Newborn heifers	heads	761,574				753,249		
Newborn bulls	heads	790,658				782,015		
Stillborn heifers	heads	38,079				37,662		
Stillborn bulls	heads	39,533				39,101		
Fallen	heads	108,699	62,625	100,000	59,526	80,874	93,534	53,671
Slaughtered	heads	329,133	239,107		598,715	199,799	395,380	689,243
Weights								
When entering activity	kg head^{-1}	625	42	44	66	625	42	44
When leaving activity	kg head^{-1}	637	667	66	723	637	667	723
Stillborn	kg head^{-1}	42				42		
Fallen animal	kg head^{-1}	631	355	55	394	631	355	383
Imported animal	kg head^{-1}	631	355	55	394	631	355	383
Slaughtered animal	kg head^{-1}	637	667		723	637	667	723

*Period from an animal enters an activity to it leaves for slaughter or it goes to another activity (e.g. when a heifer becomes a dairy cow).

Cattle turnover, stock and related parameters: Brazil

The animal turnover in the Brazilian beef system is presented in Figure 4.9. The figure shows the cattle flows between the activities and the fate of cattle leaving the activities. The parameters used for the modelling are presented in Table 4.5.

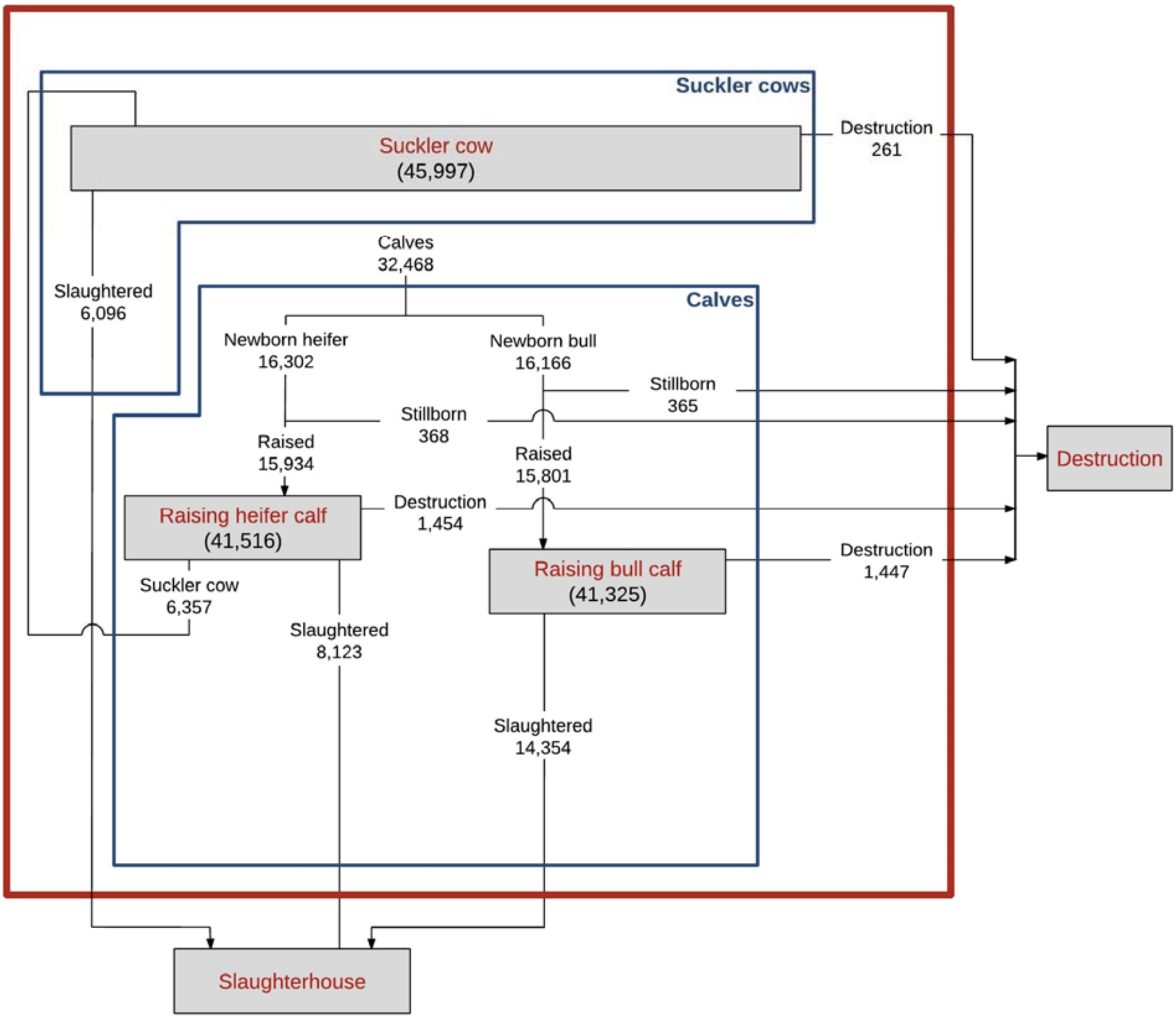

Figure 4.9: Beef system turnover in Brazil 2012. Values on arrows are flows. Bracketed values are stocks. Unit: 1000 heads.

In Dalgaard and Schmidt (2012a) we based the animal flow on cattle population reported by AgraFNP (2014) and not by the Brazilian Institute of Geography and Statistics (IBGE), since the first source was proved to have more accurate statistics (Cederberg et al. 2009a, section 3.1). Other sources, including FAOSTAT and USDA, seem to use numbers provided by IBGE what causes a mismatch between i.e. the amount of meat produced in Brazil calculated in this study and reported in FAOSTAT. Our results are, however, adjusted to match the statistics from AgraFNP (2014).

The stock sizes for 2012 were not available in AgraFNP but based on the total number of cattle in FAOSTAT (2014) we established that between 2005 and 2012 it increased by 1.99%. This percentage is used to adjust the stock sizes collected in the previous study (Dalgaard and Schmidt 2012a) so that they represent the number of suckler cows and offspring in 2012. Assuming that all the cattle categories were subjected to the same change, the stock of suckler cows increased from 45,100,000 to 45,997,483 heads. The relation between stocks and their flows (i.e. fallen, slaughtered heads) is assumed to be the same like in 2005 (Dalgaard and Schmidt 2012a).

To calculate the slaughter weights of the animals we used the same approach as used by Dalgaard and Schmidt (2012a). The total production of cattle meat in 2012 is estimated by multiplying the value from 2005 (8.15 million tonne of carcass weight, Cederberg et al. 2009a) with the increase in production observed between 2005 and 2012 (16% (IBGE 2015, Table 1092)), resulting in 9.44 million tonne. Even though the numbers can vary between two sources of statistics, the general trend in the beef production is assumed to be the same in both sources. To convert the carcass weight into live weight of slaughtered beef cattle, we assume that 73% of total cattle carcass is supplied by the beef system (Dalgaard and Schmidt 2012a) and that the carcass weight to live weight ratio is 0.55. Obtained value (12.5 million tonne of live weight) is distributed among slaughtered beef cattle with the assumption that the ratio between the slaughtered weight of suckler cows, heifers and bulls is the same as for Denmark in 2005. With this approach, the slaughter weight of suckler cow increased by 13% between 2005 and 2012 (from 422 to 479 kg) and we assume that the other weights were subjected to the same change.

The period spent in activity is assumed to be the same as in 2005 (Dalgaard and Schmidt 2012a).

Table 4.5: Parameters used for accounting for flows and stocks of animals. Brazil.

Brazil	Unit	Beef system		
Parameters		Suckler cow	Raising heifer calf	Raising bull
Stock (annual average)	heads	45,997,483	41,515,855	41,325,157
Weight gain	kg day^{-1} head^{-1}	0.0839	0.269	0.312
Period in activity*	days	2,190	1,095	1,278
Inflow				
Cow or calf	heads	6,358,056	15,933,899	15,801,117
Outflows				
Newborn heifers	heads	16,302,332		
Newborn bulls	heads	16,166,479		
Stillborn heifers	heads	368,433		
Stillborn bulls	heads	365,362		
Fallen	heads	261,726	1,453,270	1,447,030
Slaughtered	heads	6,095,893	8,122,574	14,354,087
Weights				
When entering activity	kg head^{-1}	295	45.4	45.4
When leaving activity	kg head^{-1}	479	340	445
Stillborn	kg head^{-1}	45.4		
Fallen animal	kg head^{-1}	387	193	245
Slaughtered animal	kg head^{-1}	479	398	445

*Period from an animal enters an activity to it leaves for slaughter or it goes to another activity (e.g. when a heifer becomes a dairy cow).

4.2 Inventory of feed inputs to the cattle system

The IPCC method used by Schmidt and Dalgaard (2012, equation 6.1) has been used as the default method to calculate the feed energy requirements. However, the method is related to some uncertainties, e.g. it does not consider site, animal species and feed specific conditions. Therefore, when national models, which are based on empiric data, are available, these are preferred over the IPCC model.

National models are available for calculating the feed energy requirements of German and Danish dairy cows, whereas the IPCC model is used for Swedish and British dairy cows. For German and Danish dairy cows models developed by Rösemann et al. (2013) and Kristensen (2011) respectively are used. The model of Rösemann et al. (2013) is more detailed described in the section 'Determination of feed requirements: Germany' and the model of Kristensen (2011) is described by Schmidt and Dalgaard (2012).

A comparison of feed energy required depending on the applied method in each of the four countries is presented in Table 4.6Error! Reference source not found.. Generally, the difference is small between Rösemann et al. (2013) and IPCC (2006), but larger between Kristensen (2011) and the other two models.

Table 4.6 Comparison of feed energy calculated with different methods.

Method	Unit	DE	DK	SE	UK
Kristensen (2011)	MJ head^{-1}	43,031	50,526	49,218	45,053
Rösemann et al. (2013)	MJ head^{-1}	41,281	46,809	45,444	44,293
IPCC (2006)	MJ head^{-1}	41,292	46,199	44,692	44,944

Milk yield and characteristics

The milk yields and protein and fat contents are important input parameters for calculating the feed energy requirement of dairy cows. Table 4.7 is a summary of parameters describing milk from Germany, Denmark, Sweden and United Kingdom in 2012.

Table 4.7: Milk parameters in Germany, Denmark, Sweden and United Kingdom for 2012.

Parameters	Unit	DE	DK	SE	UK
Milk yield, ex cow	kg year^{-1} head^{-1}	7,280	8,507	8,722	7,706
Milk yield, ex farm	kg year^{-1} head^{-1}	7,089	8,372	8,222	7,642
Milk, ex farm (ECM)	kg ECM year^{-1} head^{-1}	7,202	8,704	8,451	7,620
Fat	%	4.13	4.28	4.22	4.07
Protein	%	3.41	3.48	3.42	3.26

'Milk yield, ex cow', fat and protein content for Germany are obtained from Haenel et al. (2014). 'Milk collection' reported by Eurostat (2014) is divided by the number of dairy cows from Haenel et al. (2014) to calculate the 'milk yield, ex farm'.

Statistics Denmark (2014) is the source of information about all the milk parameters in Denmark. Importantly, there are some differences between the nomenclatures used in the database and presented report. 'Milk ex farm, total' in Statistics Denmark (2014) is used to calculate 'Milk yield, ex cow' while 'Delivered milk to dairies' to calculate 'Milk yield, ex farm' category in this publication.

Data collection for Sweden is based on Al-Hanbali et al. (2014). 'Milk yield, ex cow' is reported in the publication as average milk production per head. 'Milk yield, ex farm' is calculated by dividing the total Swedish milk production (Eurostat 2014) by the number of dairy cows from Al-Hanbali et al. (2014). Milk production reported in Eurostat (2014) for previous years equals values published by Cederberg et al. (2009b) as 'Delivered milk, dairies'. Therefore, we adapt Eurostat's data as 'Milk, ex farm'. Fat and protein contents are obtained from Eurostat (2014).

'Milk yield, ex cow' for United Kingdom is retrieved from Webb et al. (2014a). 'Milk yield, ex farm' is calculated based on this value and milk losses within a farm published in DEFRA (2013). Statistics for UK were originally reported in litres and are converted to kilograms using a density of 1.035 kg/L from Hui (2007, p. 373) (whole milk, 4% fat in 4.4 °C). Fat and protein contents are obtained from Eurostat (2014).

Determination of feed requirements: Germany

The national model developed by Rösemann et al. (2013) is used for modelling the net energy requirement for German dairy cows. The procedure is equivalent to the net energy system (NE system) used in the methodology described in IPCC (2006). In contrast to IPCC (2006), the approach described by Rösemann et al. (2013) includes the energy requirements for the synthesis of milk protein. Furthermore, some of the parameters are slightly different.

The starting point of the methodology of Rösemann et al. (2013) is Error! Reference source not found..

Equation 4.1

$$NEL_{tot} = \alpha \cdot (nel_m + nel_f + nel_{lc} + nel_d + nel_p + nel_g)$$

Where:

NEL_{tot} = annual net energy lactation required, MJ cow^{-1} year^{-1}
α = time units conversion factor, 365 days year^{-1}
nel_m = mean daily net energy required for maintenance, MJ cow^{-1} day^{-1}
nel_f = mean daily net energy needed to obtain food, MJ cow^{-1} day^{-1}
nel_{lc} = mean daily net energy required for lactation, MJ cow^{-1} day^{-1}
nel_d = mean daily net energy required for draft power, MJ cow^{-1} day^{-1}
nel_p = mean daily net energy required for pregnancy, MJ cow^{-1} day^{-1}
nel_g = mean daily net energy required for growth, MJ cow^{-1} day^{-1}

quation 4.2

$$nel_m = \acute{\eta}_{nel,m} \cdot w^{0.75}$$

Where:

$\acute{\eta}_{nel,m}$ = constant (0.364 MJ kg^{-1} day-^{1}). Further described by Rösemann et al. (2013, p. 123)
w = animal weight averaged over lifetime (kg cow^{-1})

The equation for calculating the net energy required to obtain energy is simplified in the current study. Rösemann et al. (2013, p. 123) apply two different activity coefficients corresponding to animal's feeding coefficient from IPCC (2006, Table 10.5) and multiply them with the fraction of N excreted on pasture.

However, in order to reduce complexity, it is decided to use one single corresponding to animal's feeding coefficient from IPCC (2006, Table 10.5). The net energy needed to obtain food (nel_f) is small and the impact on the result is limited.

Equation 4.3

$$nel_f = nel_m \cdot C_a$$

Where:

nel_m = mean daily net energy required for maintenance, MJ cow^{-1} day^{-1}. See **Error! Reference source not found.**.

C_a = coefficient corresponding to animal's feeding situation. The value of C_a is determined using IPCC (2006, Table 10.5). Calculated as average of 'stall' and 'pasture', which equals 0.085.

Equation 4.4

$$nel_{lc} = \frac{Y_M}{\alpha} \left[\left(C_{lc,1} + C_{lc,1} \cdot x_{fat,milk} + C_{lc,2} \cdot x_{XP,milk} \right) + d \right] \cdot a$$

Where:

Y_M = annual milk yield, $kg^{-1}cow$-1$year^{-1}$
α = time units conversion factor (=365 d $year^{-1}$)
$C_{lc,1}$ = constant (=0.95 MJ kg^{-1}, GfE, 2001, pg 21)
$C_{lc,2}$ = constant (=38 MJ kg^{-1}, GfE, 2001, pg 21)
$X_{fat,milk}$ = mass fraction of milk fat, kg kg^{-1}
$C_{lc,3}$ = constant (=21 MJ kg-1, GfE, 2001, pg 21)
$X_{XP,milk}$ = mass fraction of milk protein, kg kg^{-1}
d = constant (=0.1 MJ kg^{-1} d^{-1} NEL, GfE, 2001, pg 22)
a = correction factor (=1 MJ MJ^{-1}), see Rösemann et al. 2013, pg 124

NEL requirement for draft power is not included because dairy cows in Germany not are used as draught animals.

Equation 4.5

$$\mathrm{nel_p} = \frac{\mathrm{NEL_p}}{\mathrm{t_{\,ibc}}} \quad \mathrm{nel_m} \cdot \mathrm{C_a}$$

Where:

NEL_p = NEL required for pregnancy, (917 MJ $calf^{-1}$ according to Rösemann et al. (2013, p 125)
t_{ibc} = duration of the interval between calvings (calving interval), days

Equation 4.6

$$\mathrm{nel_g} = \eta_{\mathrm{nel,g}} \cdot \frac{\Delta \mathrm{w}}{\alpha}$$

Where:
$\eta_{nel,g}$ = Constant (25.5 MJ kg^{-1} NEL according to GfE, 2001, pg. 22)
Δw = weight gain (in kg cow^{-1} a^{-1})

The calculation of N requirement of dairy cows is based on Equation 6.21 in Schmidt and Dalgaard (2012). The N intake ($N_{intake(T)}$) is calculated as the sum of N excretion ($Nex_{(T)}$) and N in milk and weight gain ($N_{retention\ (T)}$). The N excretion per dairy cow per year is obtained from Strogies et al. (2014, Table 168) and equals 117 kg N per dairy cow per year. The N requirement for dairy offspring and cattle in the beef system is calculated by assuming, that the protein/feed energy ratios are the same as used by Dalgaard and Schmidt (2012a) for modelling the carbon footprint of Danish milk produced in 2005.

Parameters used for calculation of net energy requirements of German cattle are presented in Table 4.8. The total net energy (NE) is calculated as a sum of net energy used for maintenance, activity, lactation, growth etc. as described by Schmidt and Dalgaard (2012, equation 6.1).

Table 4.8: Parameters used for calculating feed requirements in Germany. (*): In Schmidt and Dalgaard (2012).

Germany Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
NE	MJ hd^{-1} day^{-}	113	32.2	12.9	46.6	Equation 6.1(*)
NE_m	MJ hd^{-1} day^{-}	42.3	22.4	8.76	31.2	Equation 6.9(*)
NE_a	MJ hd^{-1} day^{-}	3.60	1.90	0.74	2.65	Equation 6.10(*)
NE_l	MJ hd^{-1} day^{-}	62.3				Equation 6.11(*)
NE_{work}	MJ hd^{-1} day^{-}					Equation 6.12(*)
NE_p	MJ hd^{-1} day^{-}	4.23				Equation 6.13(*)
NE_g	MJ hd^{-1} day^{-}	0.70	7.94	3.40	12.8	Equation 6.15(*)
FEreq	million MJ	172,933	51,619	1,351	34,640	Equation 6.2(*)
FEreq/hd	MJ hd^{-1} yr^{-1}	41,268	11,757	4,711	16,999	Equation 6.2(*)
FEreq/hd/da	MJ hd^{-1} day^{-}	113	32.2	12.91	46.6	Equation 6.2(*)
ECM	million kg	30,181				Eurostat (2014)
ECM/head	kg hd-1 yr^{-1}	7,202				Table 4.7
C_{fi}	MJ day^{-1} kg^{-}	0.386	0.322	0.370	0.370	IPCC (2006, Table 10.4)
Weight	kg	525	286	68.0	369	Table 4.1 See text
C_a	Dim. Less	0.085	0.085	0.085	0.085	See text
Milk	kg day^{-1}	19.9				Table 4.7
Fat	%	4.13				Table 4.7
$C_{pregnancy}$	Dim. Less	0.100				IPCC (2006, Table 10.7)
BW	kg	525	286	68.0	369	Table 4.1 See text
C	Dim. less	0.800	0.800	1.20	1.20	IPCC (2006, p 10.17)
MW	kg	575	575	575	575	Table 4.1 See text
WG	kg day^{-1}	0.040	0.547	0.888	0.93	Table 4.1 See text

Determination of feed requirements: Denmark

The model of Kristensen (2011) is used to model the feed requirements of Danish dairy cows. Parameters used for calculation requirements of Danish cattle are presented in Table 4.9.

Table 4.9: Parameters used for calculating feed requirements in Denmark. (*): In Schmidt and Dalgaard (2012).

Denmark	Unit	Milk system				Source
Parameters		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
NE	MJ hd^{-1} day^{-}	127	36.8	8.49	36.9	Equation 6.1(*)
NE_m	MJ hd^{-1} day^{-}	44.4	23.7	6.93	22.8	Equation 6.9(*)
NE_a	MJ hd^{-1} day^{-}	3.78	2.02	0.589	1.94	Equation 6.10(*)
NE_l	MJ hd^{-1} day^{-}	74.2				Equation 6.11(*)
NE_{work}	MJ hd^{-1} day^{-}					Equation 6.12(*)
NE_p	MJ hd^{-1} day^{-}	4.44				Equation 6.13(*)
NE_g	MJ hd^{-1} day^{-}	0.64	11.0	0.97	12.2	Equation 6.15(*)
FEreq	million MJ	29,668	7,565	149	2,293	Equation 6.2(*)
FEreq/hd	MJ hd^{-1} yr^{-1}	50,526	13,426	3,098	13,481	Equation 6.2(*)
FEreq/hd/da	MJ hd^{-1} day^{-}	138	36.8	8.49	36.9	Equation 6.2(*)
ECM	million kg	5,111				Statistics Denmark (2014)
ECM/head	kg hd-1 yr^{-1}	8,704				Table 4.7
C_{fi}	MJ day^{-1} kg^{-}	0.386	0.322	0.370	0.370	IPCC (2006, Table 10.4)
Weight	kg	560	309	49.7	244	Table 4.2 See text
C_a	Dim. Less	0.085	0.085	0.085	0.085	See text
Milk	kg day^{-1}	23.3				Table 4.7
Fat	%	4.28				Table 4.7
$C_{pregnancy}$	Dim. Less	0.100				IPCC (2006, Table 10.7)
BW	kg	560	309	49.7	244	Table 4.2 See text
C	Dim. less	0.800	0.800	1.20	1.20	IPCC (2006, p 10.17)
MW	kg	575	575	575	575	Table 4.2 See text
WG	kg day^{-1}	0.035	0.70	0.35	1.19	Table 4.2 See text

Determination of feed requirements: Sweden

The IPCC model (IPCC 2006) is used to calculate the feed requirements of Swedish dairy cows. Parameters used for calculation of net energy requirements of Swedish cattle are presented in Table 4.10.

Table 4.10: Parameters used for calculating feed requirements in Sweden. (*): In Schmidt and Dalgaard (2012).

Sweden	Unit	Milk system				Source
Parameters		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
NE	MJ hd^{-1} day^{-}	122	29.7	11.5	37.5	Equation 6.1(*)
NE_m	MJ hd^{-1} day^{-}	38.3	20.6	7.93	27.1	Equation 6.9(*)
NE_a	MJ hd^{-1} day^{-}	3.25	1.75	0.67	2.30	Equation 6.10(*)
NE_l	MJ hd^{-1} day^{-}	75.5				Equation 6.11(*)
NE_{work}	MJ hd^{-1} day^{-}					Equation 6.12(*)
NE_p	MJ hd^{-1} day^{-}	3.83				Equation 6.13(*)
NE_g	MJ hd^{-1} day^{-}	0.88	7.31	2.86	8.12	Equation 6.15(*)
FEreq	million MJ	15,345	3,870	89.7	3,245	Equation 6.2(*)
FEreq/hd	MJ hd^{-1} yr^{-1}	44,410	10,834	4,181	13,683	Equation 6.2(*)
FEreq/hd/da	MJ hd^{-1} day^{-}	122	29.7	11.5	37.5	Equation 6.2(*)
ECM	million kg	2,920				Al-Hanbali et al. (2014)
ECM/head	kg hd-1 yr^{-1}	8,451				Table 4.7
C_{fi}	MJ day^{-1} kg^{-}	0.39	0.32	0.37	0.37	IPCC (2006, Table 10.4)
Weight	kg	459	256	59.5	306	Table 4.3 See text
C_a	Dim. Less	0.085	0.085	0.085	0.085	See text
Milk	kg day^{-1}	23.9				Table 4.7
Fat	%	4.22				Table 4.7
$C_{pregnancy}$	Dim. Less	0.100				IPCC (2006, Table 10.7)
BW	kg	459	256	59.5	306	Table 4.3 See text
C	Dim. less	0.800	0.800	1.20	1.20	IPCC (2006, p 10.17)
MW	kg	575	575	575	575	Table 4.3 See text
WG	kg day^{-1}	0.053	0.55	0.83	0.70	Table 4.3 See text

Determination of feed requirements: United Kingdom

The IPCC model (IPCC 2006) is used to calculate the feed requirements of British dairy cows. Parameters used for calculation of net energy requirements of British cattle are presented in Table 4.11.

Table 4.11: Parameters used for calculating feed requirements in United Kingdom. (*): In Schmidt and Dalgaard (2012).

United Kingdom Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
NE	MJ hd-1 day-	123	43.9	9.87	47.5	Equation 6.1(*)
NE_m	MJ hd-1 day-	48.6	26.3	7.47	32.7	Equation 6.9(*)
NE_a	MJ hd-1 day-	4.13	2.24	0.64	2.78	Equation 6.10(*)
NE_l	MJ hd-1 day-	65.4				Equation 6.11(*)
NE_{work}	MJ hd-1 day-					Equation 6.12(*)
NE_p	MJ hd-1 day-	4.86				Equation 6.13(*)
NE_g	MJ hd-1 day-	0.13	15.3	1.76	12.0	Equation 6.15(*)
FEreq	million MJ	81,423	23,647	289	24,356	Equation 6.2(*)
FEreq/hd	MJ hd-1 yr-1	44,944	16,010	3,603	17,348	Equation 6.2(*)
FEreq/hd/da	MJ hd-1 day-	123	43.9	9.87	47.5	Equation 6.2(*)
ECM	million kg	13,805				Webb et al. (2014a)
ECM/head	kg hd-1 yr-1	7,620				Table 4.7
C_{fi}	MJ day-1 kg-	0.39	0.32	0.37	0.37	IPCC (2006, Table 10.4)
Weight	kg	631	355	55.0	394	Table 4.4, see text
C_a	Dim. Less	0.085	0.085	0.085	0.085	See text
Milk	kg day-1	21.1				Table 4.7
Fat	%	4.07				Table 4.7
$C_{pregnancy}$	Dim. Less	0.100				IPCC (2006, Table 10.7)
BW	kg	631	355	55.0	394	Table 4.4, see text
C	Dim. less	0.800	0.800	1.20	1.20	IPCC (2006, p 10.17)
MW	kg	575	575	575	575	Table 4.4, see text
WG	kg day-1	0.008	0.858	0.564	0.84	Table 4.4, see text

Determination of feed requirements: Brazil

The IPCC model (IPCC 2006) is used to calculate the feed requirements of Brazilian cattle and the parameters are presented in Table 4.12.

Table 4.12: Parameters used for calculating feed requirements in Brazil. (*): In Schmidt and Dalgaard (2012).

Brazil	Unit	Beef system			Source
Parameters		Suckler cow	Raising heifer calf	Raising bull	
NE	MJ hd^{-1} day^{-}	34.5	20.9	27.6	Equation 6.1(*)
NE_m	MJ hd^{-1} day^{-}	28.1	16.7	22.9	Equation 6.9(*)
NE_a	MJ hd^{-1} day^{-}	2.39	1.42	1.95	Equation 6.10(*)
NE_l	MJ hd^{-1} day^{-}				Equation 6.11(*)
NE_{work}	MJ hd^{-1} day^{-}				Equation 6.12(*)
NE_p	MJ hd^{-1} day^{-}	2.81			Equation 6.13(*)
NE_g	MJ hd^{-1} day^{-}	1.24	2.84	2.74	Equation 6.15(*)
FEreq	million MJ	579,659	317,077	416,254	Equation 6.2(*) and 3.1
FEreq/hd	MJ hd^{-1} yr^{-1}	12,602	7,637	10,073	Equation 6.2(*) and 3.1
FEreq/hd/day	MJ hd^{-1} day^{-}	34.5	20.9	27.6	Equation 6.2(*) and 3.1
C_{fi}	MJ day^{-1} kg^{-}	0.322	0.322	0.370	IPCC (2006, Table 10.4)
Weight	kg	387	193	245	Table 4.5 See text
Ca	Dim. Less	0.085	0.085	0.085	See text
$C_{pregnancy}$	Dim. Less	0.100			IPCC (2006, Table 10.7)
BW	kg	387	193	245	Table 4.5 See text
C	Dim. less	0.800	0.800	1.20	IPCC (2006, p 10.17)
MW	kg	600	600	600	Table 4.5 See text
WG	kg day-1	0.084	0.288	0.312	Table 4.5 See text

Distribution of total feed on different feedstuffs: Germany

According to Haenel et al. (2014), there are two standard diets in Germany: mixed and grass-based. To be considered grass-based, a feed needs to contain at least 75% of grass in dairy cows' and heifers' roughage (Dämmgen et al. 2010). In the other cases the feed is categorized as a mixed diet. Given that in 2012 73% of German dairy farms used the mixed diet, this feeding system is selected for this study.

The mix diet consists of roughage, standard concentrate MLF 18/3 and rapeseed expeller. Proportion between roughage and concentrate is not reported in cited studies and is assumed to be 0.70 - 0.30 (Zehetmeier 2014). The proportion between MLF 18/3 and rapeseed expeller varies depending on the milk yield (Dämmgen et al. 2010, Table 4) and in this case is calculated for the yield of 7,280 kg of milk/head. Roughage consists of grass silage, maize silage and straw (rotation grass in our report). The proportion between rotation grass and concentrate is assumed to be the same as in De Rosa et al. (2013) and the proportions between grass and maize silage is adjusted to fulfill the cattle energy and protein requirements.

The composition of MLF 18/3 can change slightly depending on the prices of its constituents, therefore the composition used by Zehetmeier (2014) is adapted in this project. Based on Zehetmeier (2014), the diet was modified by including soybean meal in equal percentage to rapeseed meal (6.75% in total feed) and finally does not include pasture due to the intensity of milk production in Germany. The LCIs applied in the model are presented in Table 4.13.

Table 4.13: Ingredients in feed used in German cattle production and name of applied LCI in the current model.

Ingredients in feed used on German cattle farms	LCI applied in the current model
Grass silage	Rotation grass, incl. grass ensilage
Maize silage	Roughage, maize ensilage
Straw	Rotation grass, incl. grass ensilage
Rape seed expeller	Rapeseed cake/meal
Soy bean meal	Soybean meal
Sugar beet molasses	Molasses, beet
Malt germs	Malt sprouts
Maize gluten feed	Corn
Wheat bran	Wheat bran
Wheat semolina bran	Wheat bran
Triticale	Wheat
Palm-kernel cake	Palm kernel meal
Rape seed meal	Rapeseed cake/meal
Calcium carbonate	Minerals, salt etc.
Sodium chloride	Minerals, salt etc.
Others	Minerals, salt etc.

The feed intake of the German milk and beef systems is presented in Table 4.14. The intake of feed urea and minerals are presented in Table 4.38.

Table 4.14: Feed requirement and intake. Germany 2012.

Germany	**Milk system**	
Feed requirement/intake/loss	**TJ net energy**	**tons protein**
Feed requirement = feed intake		
FEreq	260,543	
FPreq		5,924,457
Feed input to animal activity		
Barley		
Wheat	2,706	32,884
Corn	12,004	120,786
Soybean meal	25,580	1,250,005
Rape seed/cake	25,947	975,892
Molasses	4,602	78,065
Palm kernel meal	4,232	110,835
Wheat bran	11,463	301,416
Malt sprouts	4,783	190,072
Feed urea		
Permanent grass	5,480	162,959
Roughage, maize ensilage	106,172	1,218,838
Rotation grass, incl. grass ensilage	80,843	1,952,872
Total feed intake	**283,811**	**6,394,626**
Feed loss = feed input to animal activity – feed intake		
Feed loss, total	23,267	470,169

Distribution of total feed on different feedstuffs: Denmark

- Composition of the feed is assumed to be the same as in 2005 (Dalgaard and Schmidt 2012a) with few new assumptions: In 2005 distillers grains included in the model as soybean meal but now are an independent category.
- The amount of permanent grass is estimated based on the fact that in 2005 it covered 1.64% and 21.9% of energy in the milk and beef system, respectively. We estimate that this percentage did not change in 2012.
- For both the milk and beef system, intake of minerals and feed urea per cow (including the offspring) is assumed to be the same as in 2012.

The feed intake of the Danish milk and beef systems is presented in Table 4.15. The intake of feed urea and minerals are presented in Table 4.39.

Table 4.15: Feed requirement and intake. Denmark.

Denmark	Milk system	
Feed requirement/intake/loss	TJ net energy	tons protein
Feed requirement = feed intake		
FEreq	39,675	
FPreq		898,001
Feed input to animal activity		
Barley	5,676	70,623
Corn	323	3,247
Soybean meal	2,601	127,115
Rape seed/cake	2,428	91,309
Sunflower meal	1,714	85,411
Beet pulp, dried	596	7,313
Molasses	161	2,723
Palm oil	481	
Wheat bran	162	4,264
DDGS	34	1,289
Feed urea		15,768
Permanent grass	642	19,078
Roughage, maize ensilage	11,157	128,087
Rotation grass, incl. grass ensilage	17,250	416,706
Total feed intake	**43,224**	**972,934**
Feed loss = feed input to animal activity – feed intake		
Feed loss, total	3,550	74,932

Distribution of total feed on different feedstuffs: Sweden

Composition of feed for dairy cows is based on diet described in Henriksson et al. (2014) as a typical in Northern region of Sweden. The only modification concerns the share of rotation grass and oat ensilage, which is calculated to fulfill the energy and protein requirements (Dalgaard and Schmidt 2012a). Opposed to Germany, Denmark and United Kingdom, oat ensilage is used instead of maize ensilage in Sweden. In case of beef system, we apply the same diet as in 2005 (Dalgaard and Schmidt 2012a) and we assume the same intake of minerals per MJ of energy. The LCIs used in the model are presented in Table 4.16.

Table 4.16: Ingredients in feed used in Swedish cattle production and name of applied LCI in the current model.

Ingredients in feed used on Swedish cattle farms	LCI applied in the current model
Grass/clover silage	Roughage, oat ensilage
Pasture	Rotation grass, incl. grass ensilage
Mineral and lime	Minerals, salt etc.

The feed intake of the Swedish milk and beef systems is presented in Table 4.17. The intake of feed urea and minerals are presented in Table 4.40.

Table 4.17: Feed requirement and intake. Sweden.

Sweden Feed requirement/intake/loss	Milk system TJ net energy	 tons protein
Feed requirement = feed intake		
FEreq	22,549	
FPreq		549,464
Feed input to animal activity		
Barley	1,736	21,596
Wheat	618	7,515
Oat	986	14,137
Corn	33	335
Soybean meal	1,604	78,387
Rape seed/cake	1,436	54,002
Beet pulp	92	1,199
Molasses	116	1,970
Palm oil	1,208	
Palm kernel meal	312	8,163
Wheat bran	339	8,914
Permanent grass	2,642	78,582
Roughage, oat ensilage	796	9,134
Rotation grass, incl. grass ensilage	12,372	298,852
Total feed intake	**24,290**	**582,785**
Feed loss = feed input to animal activity – feed intake		
Feed loss, total	1,741	33,322

Distribution of total feed on different feedstuffs: United Kingdom

In case of United Kingdom, we adapt the feed composition from British National Inventory Report (Webb et al. 2014a) and modify the share of grass and maize ensilage to fulfil the energy and protein requirements as described in Dalgaard and Schmidt (2012a). The feed for suckler cows is based on composition of Danish suckler feed from 2005, and for calculating feed urea and minerals, we assume that their intake per MJ of required energy is the same as in Denmark 2005 (Dalgaard and Schmidt 2012a). The LCIs used in the model are presented in Table 4.18.

Table 4.18: Ingredients in feed used in British cattle production and name of applied LCI in the current model.

Ingredients in feed used on British cattle farms	LCI applied in the current model
Fresh grass (grazed) - all species	Permanent grass
Grass silage	Rotation grass, incl. grass ensilage
Maize silage	Roughage, maize ensilage
Barley grain	Barley
Maize gluten feed	Wheat
Sugar beet pulp (molasses)	Beet pulp, dried
Wheat feed	Wheat
Wheat grain	Wheat
Rapeseed meal	Rapeseed cake/meal
Soya bean meal	Soybean meal
Sunflower meal	Sunflower meal
Vitamins and minerals	Minerals, salt etc.

The feed intake of the British milk and beef systems is presented in Table 4.19. The intake of feed urea and minerals are presented in Table 4.41.

Table 4.19: Feed requirement and intake. United Kingdom.

United Kingdom	Milk system	
Feed requirement/intake/loss	TJ net energy	tons protein
Feed requirement = feed intake		
FEreq	129,714	
FPreq		2,838,147
Feed input to animal activity		
Barley	16,081	200,087
Wheat	10,610	128,955
Soybean meal	2,669	130,417
Rape seed/cake	9,074	341,279
Sunflower meal	1,632	81,322
Beet pulp, dried	1,906	23,402
Feed urea		
Permanent grass	9,633	286,473
Roughage, maize ensilage	21,565	247,561
Rotation grass, incl. grass ensilage	67,555	1,631,867
Total feed intake	**140,725**	**3,071,363**
Feed loss = feed input to animal activity – feed intake		
Feed loss, total	11,011	233,216

Distribution of total feed on different feedstuffs: Brazil

The feed intake of the Brazilian beef system is presented in Table 4.20 and it is modelled using the same approach as for the Brazilian beef system described by Dalgaard and Schmidt (2012a). It is assumed there is not feed loss, as the Brazilian cattle only consume permanent grass.

Table 4.20: Feed requirement and intake. Brazil 2012.

Brazil	Beef system	
Feed requirement/intake	**TJ net energy**	**tons protein**
Feed requirement = feed intake		
FEreq	1,312,990	
FPreq		47,618,120
Feed input to animal activity		
Permanent grass	1,312,990	47,618,120
Total feed intake	**1,312,990**	**47,618,120**

4.3 Inventory of other inputs and materials for treatment in the cattle system

Uses of energy, transport, capital goods and services

The amount of diesel (per head), electricity (per kg milk), and transport as well as the uses of capital goods and services have been collected and modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

The uses of diesel, electricity, transport, capital goods and services in the cattle systems are presented in the summary of LCI in section 4.5.

Material for treatment: Manure treatment

The amount of manure to treatment is inventoried in section 4.5 (Table 4.38 to Table 4.42). The treatment of manure is included in crop cultivation for switches 2, 3 and 4 (average/allocation, PAS2050 and IDF). For switch 1: ISO 14040/44, manure treatment is included in the animal activities. The LCI data for the treatment activity are documented in Dalgaard and Schmidt (2012a) which present an inventory for 2005. We have assumed that the efficiency of the use of nutrients in the manure has not changed from 2005 to 2012. This is based on Plantedirektoratet (2011, p 41), where data on utilisation of nitrogen in different types of cattle manure are the same as the data presented by Plantedirektoratet (2004).

The distribution between the different types of manure is modelled and presented in section 4.4.

Material for treatment: Destruction of fallen cattle

The amount of animals to destruction are inventoried in section 4.1. The treatment activity is modelled by Dalgaard and Schmidt (2012a) and the same data have been applied here.

4.4 Emissions

Methane emissions from enteric fermentation: Germany

The parameters used for calculation of methane emissions from enteric fermentation are presented in Table 4.21. The emission factor (EF) is calculated from the gross energy intake (GE), which again is calculated from the net energy intake (Schmidt et al. 2012, Section 6.4). DE% (digestibility of feed in percent) is calculated as a weighted average of DE% for each of the used feedstuffs.

Table 4.21: Parameters used for calculating methane emissions from enteric fermentation in Germany. (*): In Schmidt and Dalgaard (2012).

Germany	Unit	Dairy system				Source
Para-meters		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
EF	kg CH_4 hd^{-1} yr^{-1}	124	35.4	14.2	51.1	Equation 7.7(*)
GE	MJ hd^{-1} day^{-1}	291	83.0	33.2	136	Equation 7.2 and 7.3 (*)
Ym	%	6.50	6.50	6.50	6.50	IPCC (2006, Table 10.12)
NE_m	MJ day^{-1}	42.3	22.4	8.76	31.2	Table 4.8
NE_a	MJ day^{-1}	3.60	1.90	0.745	2.65	Table 4.8
NE_l	MJ day^{-1}	62.3				Table 4.8
NE_{work}	MJ day^{-1}					Table 4.8
NE_p	MJ day^{-1}	4.23				Table 4.8
NE_g	MJ day^{-1}	0.70	7.94	3.40	12.8	Table 4.8
REM	Dim. Less	0.537	0.537	0.537	0.537	Equation 7.14(*)
REG	Dim. Less	0.346	0.346	0.346	0.346	Equation 7.16(*)
DE%	%	73.3	73.3	73.3	73.3	See text

Methane emissions from enteric fermentation: Denmark

The parameters used for calculation of methane emissions from enteric fermentation are presented in Table 4.22. The emission factor (EF) is calculated from the gross energy intake (GE), which again is calculated from the net energy intake (Schmidt et al. 2012, Section 6.4). DE% (digestibility of feed in percent) is calculated as a weighted average of DE% for each of the used feedstuffs.

Table 4.22: Parameters used for calculating methane emissions from enteric fermentation in Denmark. (*): In Schmidt and Dalgaard (2012).

Denmark	Unit	Milk system				Source
Para-meters		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
EF	kg CH_4 hd^{-1} yr^{-1}	151	40.1	9.24	40.2	Equation 6.7(*)
GE	MJ hd^{-1} day^{-1}	354	94.0	21.7	109	See text
Ym	%	6.50	6.50	6.50	6.50	IPCC (2006, Table 10.12)
NE_m	MJ day^{-1}	44.4	23.7	6.93	22.8	Table 4.9
NE_a	MJ day^{-1}	3.78	2.02	0.589	1.94	Table 4.9
NE_l	MJ day^{-1}	74.2				Table 4.9
NE_{work}	MJ day^{-1}					Table 4.9
NE_p	MJ day^{-1}	4.44				Table 4.9
NE_g	MJ day^{-1}	0.64	11.0	0.968	12.2	Table 4.9
REM	Dim. Less	0.538	0.538	0.538	0.538	Equation 6.14(*)
REG	Dim. Less	0.348	0.348	0.348	0.348	Equation 6.16(*)
DE%	%	73.9	73.9	73.9	73.9	See text

Methane emissions from enteric fermentation: Sweden

The parameters used for calculation of methane emissions from enteric fermentation are presented in Table 4.23. The emission factor (EF) is calculated from the gross energy intake (GE), which again is calculated from the net energy intake (Schmidt et al. 2012, Section 6.4). DE% (digestibility of feed in percent) is calculated as a weighted average of DE% for each of the used feedstuffs.

Table 4.23: Parameters used for calculating methane emissions from enteric fermentation in Sweden. (*): In Schmidt and Dalgaard (2012).

Sweden Para-meters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
EF	kg CH_4 hd^{-1} yr^{-1}	134	32.8	12.7	41.4	Equation 6.7(*)
GE	MJ hd^{-1} day^{-1}	315	77.0	29.7	107	See text
Ym	%	6.50	6.50	6.50	6.50	IPCC (2006, Table 10.12)
NE_m	MJ day^{-1}	38.3	20.6	7.93	27.1	Table 4.10
NE_a	MJ day^{-1}	3.25	1.75	0.674	2.30	Table 4.10
NE_l	MJ day^{-1}	75.5				Table 4.10
NE_{work}	MJ day^{-1}					Table 4.10
NE_p	MJ day^{-1}	3.83				Table 4.10
NE_g	MJ day^{-1}	0.88	7.31	2.86	8.12	Table 4.10
REM	Dim. Less	0.537	0.537	0.537	0.537	Equation 6.14(*)
REG	Dim. Less	0.345	0.345	0.345	0.345	Equation 6.16(*)
DE%	%	73.2	73.2	73.2	73.2	See text

Methane emissions from enteric fermentation: United Kingdom

The parameters used for calculation of methane emissions from enteric fermentation are presented in Table 4.24. The emission factor (EF) is calculated from the gross energy intake (GE), which again is calculated from the net energy intake (Schmidt et al. 2012, Section 6.4). DE% (digestibility of feed in percent) is calculated as a weighted average of DE% for each of the used feedstuffs.

Table 4.24: Parameters used for calculating methane emissions from enteric fermentation in United Kingdom. (*): In Schmidt and Dalgaard (2012).

United Kingdom Para-meters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
EF	kg CH_4 hd^{-1} yr^{-1}	135	48.2	10.9	52.2	Equation 6.7(*)
GE	MJ hd^{-1} day^{-1}	317	113	25.5	136	See text
Ym	%	6.50	6.50	6.50	6.50	IPCC (2006, Table 10.12)
NE_m	MJ day^{-1}	48.6	26.3	7.47	32.7	Table 4.11
NE_a	MJ day^{-1}	4.13	2.24	0.635	2.78	Table 4.11
NE_l	MJ day^{-1}	65.4				Table 4.11
NE_{work}	MJ day^{-1}					Table 4.11
NE_p	MJ day^{-1}	4.86				Table 4.11
NE_g	MJ day^{-1}	0.13	15.3	1.76	12.0	Table 4.11
REM	Dim. Less	0.538	0.538	0.538	0.538	Equation 6.14(*)
REG	Dim. Less	0.348	0.348	0.348	0.348	Equation 6.16(*)
DE%	%	73.8	73.8	73.8	73.8	See text

Methane emissions from enteric fermentation: Brazil

The parameters used for calculation of methane emissions from enteric fermentation are presented in Table 4.25. The emission factor (EF) is calculated from the gross energy intake (GE), which again is calculated from the net energy intake (Schmidt et al. 2012, Section 6.4). DE% (digestibility of feed in percent) is calculated as a weighted average of DE% for each of the used feedstuffs.

The digestibility of permanent grass in Brazil is obtained by multiplying the digestible energy of Danish grass as of Møller et al. (2005) by the relative difference between feed digestibility of feed in South America (63%) and Western Europe (77%) as of Gerber et al. (2013, p. 71 and 76). The adjustment factor is 63% / 77% = 82%.

Table 4.25: Parameters used for calculating methane emissions from enteric fermentation in Brazil. (*): In Schmidt and Dalgaard (2012).

Brazil Para-meters	Unit	Beef system			Source
		Suckler cow	Raising heifer calf	Raising bull	
EF	kg CH_4 hd^{-1} yr^{-1}	49.3	29.9	39.4	Equation 6.7(*)
GE	MJ hd^{-1} day^{-1}	116	70.1	92.5	See text
Ym	%	6.50	6.50	6.50	IPCC (2006, Table 10.12)
NE_m	MJ day^{-1}	28.1	16.7	22.9	Table 4.12
NE_a	MJ day^{-1}	2.39	1.42	1.95	Table 4.12
NE_l	MJ day^{-1}				Table 4.12
NE_{work}	MJ day^{-1}				Table 4.12
NE_p	MJ day^{-1}	2.81			Table 4.12
NE_g	MJ day^{-1}	1.24	2.84	2.7	Table 4.12
REM	Dim. Less	0.49	0.49	0.49	Equation 6.14(*)
REG	Dim. Less	0.27	0.27	0.27	Equation 6.16(*)
DE%	%	58.6	58.6	58.6	See text

Methane and nitrous oxide emissions from manure management: Germany

Data on German manure systems are from Haenel et al. (2014). Parameters used for calculating CH_4 emissions from manure management in Germany are presented in Table 4.26.

Table 4.26: Parameters used for calculating CH_4 emissions from German manure management systems (MMS). (*): In Schmidt and Dalgaard (2012).

Germany Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$EF_{(T)}$	kg CH_4 hd^{-1} yr^{-1}	26.6	5.99	3.81	9.75	Equation 6.4(*)
$VS_{(T)}$	kg DM hd^{-1} day^{-1}	4.46	1.27	0.509	1.84	Equation 6.5(*)
$B_{o(T)}$	m^3 CH_4 (kg VS excreted)$^{-1}$	0.240	0.180	0.180	0.180	IPCC (2006, p 10.77-8)
$MCF_{(Pasture,10°C)}$	%	1	1	1	1	IPCC (2006, Table 10.17)
$MCF_{(Liquid, 10°C)}$	%	10	10	10	10	
$MCF_{(Solid, 10°C)}$	%	2	2	2	2	
$MCF_{(Deep bed., 10°C)}$	%	17	17	17	17	
$MS_{(Pasture, 10°C)}$	Dim. Less	10.6	20.4		3	Haenel et al. (2014).
$MS_{(Liquid, 10°C)}$	Dim. Less	73.7	43.4		62.8	
$MS_{(Solid, 10°C)}$	Dim. Less					
$MS_{(Deep bed., 10°C)}$	Dim. Less	15.7	36.2	100	33.7	
GE	MJ day^{-1}	291	83.0	33.2	120	Table 4.21
DE%	%	73.3	73.3	73.3	73.3	Table 4.21
UE	Dim. Less	0.04	0.04	0.04	0.04	IPCC (2006, eq 10.24)
ASH	Dim. Less	8.00	8.00	8.00	8.00	IPCC (2006, p 10.42)

Parameters used for calculation of N_2O emissions from manure management in Germany are presented in Table 4.27.

Table 4.27: Parameters used for calculating N_2O emissions from German manure management in milk system. (*): In Schmidt and Dalgaard (2012).

Germany Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$N_2O_{(mm)}$	kg N_2O yr^{-1}	4,811,263	1,748,849		1,093,926	Equation 6.19(*)
$N_2O_{D(mm)}$	kg N_2O yr^{-1}	4,167,156	1,475,656		930,602	Equation 6.20(*)
$N_2O_{G(mm)}$	kg N_2O yr^{-1}	644,108	273,193		163,324	Equation 6.21(*)
N_T	heads	4,190,485	4,390,626		2,037,706	Table 4.1
$N_2O_{(mm)}$/head	kg N_2O hd^{-1} yr^{-1}	1.15	0.398	0.223	0.537	$N_2O_{(mm)}$/ N_T
$Nex_{(T)}$	kg N hd^{-1} yr^{-1}	117	35.5	11.7	43.0	Equation 6.21 (*)
$MS_{(Liquid)}$	Dim. Less	0.706	0.389		0.577	From MS parameters in Table 4.26
$MS_{(Solid)}$	Dim. Less					
$MS_{(Deep bed.)}$	Dim. Less	0.189	0.407	1.00	0.388	
$EF_{3(Liquid/solid)}$	kg N_2O-N kg N^{-1}	0.005	0.005	0.005	0.005	IPCC (2006, Table 10.21)
$EF_{3(Solid storage)}$	kg N_2O-N kg N^{-1}	0.005	0.005	0.005	0.005	
$EF_{3(deep bed.)}$	kg N_2O-N kg N^{-1}	0.01	0.01	0.01	0.01	
$N_{intake(T)}$	kg N hd^{-1} yr^{-1}	157	40.7	20.1	51.8	From protein content in feed
$N_{retention(T)}$	kg N hd^{-1} yr^{-1}	40.1	5.19	8.43	8.86	Equation 6.22 (*)
N_{milk}	kg N hd^{-1} yr^{-1}	39.7				Equation 6.22 (*)
$N_{weight gain}$	kg N hd^{-1} yr^{-1}	0.375	5.19	8.43	8.86	Equation 6.22 (*)
$N_{volatilization-MMS}$	kg N yr^{-1}	9.78	3.96	2.51	5.10	Equation 6.22 (*)
EF_4	kg N_2O-N kg N^{-1}	0.01	0.01	0.01	0.01	IPCC (2006, Table 11.3)

The N inputs, outputs and emissions related to the German milk system in 2012 are presented in Table 4.28. The N balance is calculated as N inputs minus the sum of N outputs and N emissions. When the N balance equals 0, it means all N is accounted for.

Table 4.28: N balances and emissions related to the German milk system. Unit: Kg N hd^{-1} yr^{-1}.

Germany Parameter	Milk system Dairy cow	 Raising heifer calf	 Raising bull calf	 Raising bull
N inputs				
Feed	157	40.7	20.1	51.8
N outputs				
Milk	39.7			
Weight gain, live weight	0.375	5.19	8.43	8.86
Manure leaving storage	94.1	24.1	9.03	36.1
Manure excreted outdoor	12.4	7.2		1
N emissions				
Ammonia from stable	7.86	3.47	2.32	4.36
Ammonia from storage	1.92	0.492	0.184	0.736
N_2O-N_{direct}	0.633	0.214	0.117	0.291
N balance*	0	0	0	0

* N balance = N inputs – N outputs – N emissions

Methane and nitrous oxide emissions from manure management: Denmark

The distribution of the different housing types in Denmark is from Mikkelsen et al. (2014). Data representing the year 2011 are used, because data from 2012 not are available. Parameters used for calculation of CH_4 emissions from manure management in Denmark are presented in Table 4.29.

Table 4.29: Parameters used for calculating CH_4 emissions from Danish manure management systems. MMS: Manure Management System. (*): In Schmidt and Dalgaard (2012).

Denmark Parameters	Unit	Milk system Dairy cow	 Raising heifer calf	 Raising bull calf	 Raising bull	Source
$EF_{(T)}$	kg CH_4 hd^{-1} yr^{-1}	30.1	4.82	0.971	8.99	Equation 6.17(*)
$VS_{(T)}$	kg DM hd^{-1} day^{-1}	5.30	1.41	0.325	1.41	Equation 6.18(*)
$B_{o(T)}$	m^3 CH_4 (kg VS excreted)$^{-1}$	0.240	0.180	0.180	0.180	IPCC (2006, p 10.77-8)
$MCF_{(Pasture,10°C)}$	%	1	1	1	1	IPCC (2006, Table 10.17)
$MCF_{(Liquid, 10°C)}$	%	10	10	10	10	
$MCF_{(Solid, 10°C)}$	%	2	2	2	2	
$MCF_{(Deep bed., 10°C)}$	%	17	17	17	17	
$MS_{(Pasture, 10°C)}$	Dim. Less	4.93	36.2			Mikkelsen et al. (2014)
$MS_{(Liquid, 10°C)}$	Dim. Less	89.4	45.6	58.0	34.5	
$MS_{(Solid, 10°C)}$	Dim. Less	1.90	1.60	7.00	1.00	
$MS_{(Deep bed., 10°C)}$	Dim. Less	3.80	16.6	5.00	64.5	
GE	MJ day^{-1}	354	94.0	21.7	94.3	Table 4.22
DE%	%	73.9	73.9	73.9	73.9	Table 4.22
UE	Dim. Less	0.04	0.04	0.04	0.04	IPCC (2006, eq 10.24)
ASH	Dim. Less	8.00	8.00	8.00	8.00	IPCC (2006, p 10.42)

The parameter values used for calculation of N_2O emissions from manure management systems are presented in Table 4.30.

Table 4.30: Parameters used for calculating N_2O emissions from Danish manure management in milk system. (*): In Schmidt and Dalgaard (2012).

Denmark Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$N_2O_{(mm)}$	kg N_2O yr^{-1}	725,582	168,018	4,570	74,295	Equation 6.19(*)
$N_2O_{D(mm)}$	kg N_2O yr^{-1}	641,640	147,210	4,068	67,558	Equation 6.20(*)
$N_2O_{G(mm)}$	kg N_2O yr^{-1}	83,941	20,808	503	6,737	Equation 6.21(*)
N_T	heads	587,189	563,441	48,124	170,063	Table 4.2
$N_2O_{(mm)}$/head	kg N_2O hd^{-1} yr^{-1}	1.24	0.298	0.095	0.437	$N_2O_{(mm)}$/ N_T
$Nex_{(T)}$	kg N hd^{-1} yr^{-1}	139	39.9	9.89	29.8	Equation 6.21 (*)
$MS_{(Liquid)}$	Dim. Less	0.885	0.429	0.817	0.297	From MS parameters in Table 4.29
$MS_{(Solid)}$	Dim. Less	0.018	0.014	0.095	0.008	
$MS_{(Deep\ bed.)}$	Dim. Less	0.047	0.195	0.088	0.695	
$EF_{3(Liquid/solid)}$	kg N_2O-N kg N^{-1}	0.005	0.005	0.005	0.005	IPCC (2006, Table 10.21)
$EF_{3(Solid\ storage)}$	kg N_2O-N kg N^{-1}	0.005	0.005	0.005	0.005	
$EF_{3(deep\ bed.)}$	kg N_2O-N kg N^{-1}	0.01	0.01	0.01	0.01	
$N_{intake(T)}$	kg N hd^{-1} yr^{-1}	187	46.5	13.2	41.1	From protein content in feed
$N_{retention(T)}$	kg N hd^{-1} yr^{-1}	47.7	6.63	3.32	11.3	Equation 6.22 (*)
N_{milk}	kg N hd^{-1} yr^{-1}	47.4				Equation 6.22 (*)
$N_{weight\ gain}$	kg N hd^{-1} yr^{-1}	0.330	6.63	3.32	11.3	Equation 6.22 (*)
$N_{volatilization\text{-}MMS}$	kg N hd^{-1} yr^{-1}	9.10	2.35	0.665	2.52	Equation 6.22 (*)
EF_4	kg N_2O-N kg N^{-1}	0.01	0.01	0.01	0.01	IPCC (2006, Table 11.3)

The N inputs, outputs and emissions related to the Danish milk system are presented in Table 4.31. The N balance is calculated as N inputs minus the sum of N outputs and N emissions. When the N balance equals 0, it means all N is accounted for.

Table 4.31: N balances and emissions related to the Danish milk system. Unit: Kg N hd^{-1} yr^{-1}.

Denmark Parameter	Milk system			
	Dairy cow	Raising heifer calf	Raising bull calf	Raising bull
N inputs				
Feed	187	46.5	13.2	41.1
N outputs				
Milk	47.4			
Weight gain, live weight	0.330	6.63	3.32	11.3
Manure leaving storage	123	22.9	9.17	27.1
Manure excreted outdoor	6.87	14.4		
N emissions				
Ammonia from stable	6.59	1.88	0.477	1.97
Ammonia from storage	2.50	0.468	0.187	0.552
N_2O-N_{direct}	0.695	0.166	0.054	0.253
N balance*	0	0	0	0

* N balance = N inputs – N outputs – N emissions

Methane and nitrous oxide emissions from manure management: Sweden

Data on Swedish manure systems are based on Al-Hanbali et al. (2014). Parameters used for calculation of CH_4 emissions from manure management in Sweden are presented in Table 4.32.

Table 4.32: Parameters used for calculating CH_4 emissions from Swedish manure management systems (MMS). (*): In Schmidt and Dalgaard (2012).

Sweden Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$EF_{(T)}$	kg CH_4 hd^{-1} yr^{-1}	19.5	2.88	1.11	3.63	Equation 6.17(*)
$VS_{(T)}$	kg DM hd^{-1} day^{-1}	4.84	1.18	0.456	1.49	Equation 6.18(*)
$B_{o(T)}$	m^3 CH_4 (kg VS excreted)$^{-1}$	0.240	0.180	0.180	0.180	IPCC (2006, p 10.77-8)
$MCF_{(Pasture,10°C)}$	%	1	1	1	1	IPCC (2006, Table 10.17)
$MCF_{(Liquid, 10°C)}$	%	10	10	10	10	
$MCF_{(Solid, 10°C)}$	%	2	2	2	2	
$MCF_{(Deep bed., 10°C)}$	%	17	17	17	17	
$MS_{(Pasture, 10°C)}$	Dim. Less	24.0	46.0	46.0	46	Al-Hanbali et al. (2014).
$MS_{(Liquid, 10°C)}$	Dim. Less	62.0	18.0	18.0	18.0	
$MS_{(Solid, 10°C)}$	Dim. Less	13.0	19.0	19.0	19.0	
$MS_{(Deep bed., 10°C)}$	Dim. Less	1.00	17.0	17.0	17.0	
GE	MJ day^{-1}	315	77.0	29.7	97.2	Table 4.23
DE%	%	73.2	73.2	73.2	73.2	Table 4.23
UE	Dim. Less	0.04	0.04	0.04	0.04	IPCC (2006, eq 10.24)
ASH	Dim. Less	8.00	8.00	8.00	8.00	IPCC (2006, p 10.42)

The parameter values used for calculation of N_2O emissions from manure management systems are presented in Table 4.33.

Table 4.33: Parameters used for calculating N_2O emissions from Swedish manure management in milk system. (*): In Schmidt and Dalgaard (2012).

Sweden Parameters	Unit	Milk system				Source
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$N_2O_{(mm)}$	kg N_2O yr^{-1}	314,979	71,684	1,370	51,622	Equation 6.19(*)
$N_2O_{D(mm)}$	kg N_2O yr^{-1}	280,112	61,192	1,169	44,066	Equation 6.20(*)
$N_2O_{G(mm)}$	kg N_2O yr^{-1}	34,868	10,492	200	7,556	Equation 6.21(*)
N_T	heads	345,527	357,201	21,441	237,129	Table 4.3
$N_2O_{(mm)}$/head	kg N_2O hd^{-1} yr^{-1}	0.912	0.201	0.064	0.218	$N_2O_{(mm)}$/ N_T
$Nex_{(T)}$	kg N hd^{-1} yr^{-1}	134	34.6	11.0	37.5	Equation 6.21 (*)
$MS_{(Liquid)}$	Dim. Less	0.622	0.144	0.144	0.144	From MS parameters in Table 4.32.
$MS_{(Solid)}$	Dim. Less	0.126	0.146	0.146	0.146	
$MS_{(Deep bed.)}$	Dim. Less	0.013	0.170	0.17	0.170	
$EF_{3(Liquid/solid)}$	kg N_2O-N kg N^{-1}	0.005	0.005	0.005	0.005	IPCC (2006, Table 10.21)
$EF_{3(Solid storage)}$	kg N_2O-N kg N^{-1}	0.005	0.005	0.005	0.005	
$EF_{3(deep bed.)}$	kg N_2O-N kg N^{-1}	0.01	0.01	0.01	0.01	
$N_{intake(T)}$	kg N hd^{-1} yr^{-1}	182	39.8	18.9	44.2	From protein content in feed
$N_{retention(T)}$	kg N hd^{-1} yr^{-1}	48.2	5.18	7.87	6.67	Equation 6.22 (*)
N_{milk}	kg N hd^{-1} yr^{-1}	47.7				Equation 6.22 (*)
$N_{weight gain}$	kg N hd^{-1} yr^{-1}	0.503	5.18	7.87	6.67	Equation 6.22 (*)
$N_{volatilization-MMS}$	kg N hd^{-1} yr^{-1}	6.42	1.87	0.595	2.03	Equation 6.22 (*)
EF_4	kg N_2O-N kg N^{-1}	0.01	0.01	0.01	0.01	IPCC (2006, Table 11.3)

The N inputs, outputs and emissions related to the Swedish milk system are presented in Table 4.34. The N balance is calculated as N inputs minus the sum of N outputs and N emissions. When the N balance equals 0, it means all N is accounted for.

Table 4.34: N balances and emissions related to the Swedish milk system. Unit: Kg N hd^{-1} yr^{-1}.

Sweden	Milk system			
	Dairy cow	Raising heifer calf	Raising bull calf	Raising bull
N inputs				
Feed	182	39.8	18.9	44.2
N outputs				
Milk	47.7			
Weight gain, live weight	0.503	5.18	7.87	6.7
Manure leaving storage	94.6	13.9	4.44	15.1
Manure excreted outdoor	32.1	18.7	5.95	20.3
N emissions				
Ammonia from stable	4.49	1.58	0.504	1.72
Ammonia from storage	1.93	0.285	0.091	0.309
N_2O-N_{direct}	0.516	0.109	0.035	0.118
N balance*	0	0	0	0

Methane and nitrous oxide emissions from manure management: United Kingdom

The distribution of the different housing types in United Kingdom is from Webb et al. (2014a, Table A.3.5.11). Parameters used for calculation of CH_4 emissions from manure management in United Kingdom are presented in Table 4.35.

Table 4.35: Parameters used for calculating CH_4 emissions from British manure management systems (MMS). (*): In Schmidt and Dalgaard (2012).

United Kingdom	Unit	Milk system				Source
Parameters		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$EF_{(T)}$	kg CH_4 hd^{-1} yr^{-1}	17.5	3.84	1.39	6.69	Equation 6.17(*)
$VS_{(T)}$	kg DM hd^{-1} day^{-1}	4.79	1.70	0.384	1.85	Equation 6.18(*)
$B_{o(T)}$	m^3 CH_4 (kg VS excreted)$^{-1}$	0.240	0.180	0.180	0.180	IPCC (2006, p 10.77-8)
$MCF_{(Pasture,10°C)}$	%	1	1	1	1	IPCC (2006, Table 10.17)
$MCF_{(Liquid, 10°C)}$	%	10	10	10	10	
$MCF_{(Solid, 10°C)}$	%	2	2	2	2	
$MCF_{(Deep bed., 10°C)}$	%	17	17	17	17	
$MS_{(Pasture, 10°C)}$	Dim. Less	45.1	69.0	54.8	54.8	Webb et al. (2014a)
$MS_{(Liquid, 10°C)}$	Dim. Less	41.0	9.7			
$MS_{(Solid, 10°C)}$	Dim. Less	4.60	1.10			
$MS_{(Deep bed., 10°C)}$	Dim. Less	9.30	20.2	45.2	45.2	
GE	MJ day^{-1}	317	113	25.5	122.6	Table 4.24
DE%	%	73.8	73.8	73.8	73.8	Table 4.24
UE	Dim. Less	0.04	0.04	0.04	0.04	IPCC (2006, eq 10.24)
ASH	Dim. Less	8.00	8.00	8.00	8.00	IPCC (2006, p 10.42)

The parameter values used for calculation of N_2O emissions from manure management systems are presented in Table 4.36.

Table 4.36: Parameters used for calculating N_2O emissions from British manure management in milk system. (*): In Schmidt and Dalgaard (2012).

United Kingdom	Unit	Milk system				Source
Parameters		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull	
$N_2O_{(mm)}$	kg N_2O yr^{-1}	1,340,349	347,394	6,930	543,849	Equation 6.19(*)
$N_2O_{D(mm)}$	kg N_2O yr^{-1}	1,162,066	289,768	5,703	447,509	Equation 6.20(*)
$N_2O_{G(mm)}$	kg N_2O yr^{-1}	178,283	57,626	1,228	96,339	Equation 6.21(*)
N_T	heads	1,811,646	1,477,000	80,257	1,403,917	Table 4.4
$N_2O_{(mm)}$/head	kg N_2O hd^{-1} yr^{-}	0.740	0.235	0.086	0.387	$N_2O_{(mm)}$/ N_T
$Nex_{(T)}$	kg N hd^{-1} yr^{-1}	124	47.3	10.0	44.9	Equation 6.21 (*)
$MS_{(Liquid)}$	Dim. Less	0.394	0.083			
$MS_{(Solid)}$	Dim. Less	0.043	0.009			From MS parameters in Table 4.24.
$MS_{(Deep\ bed.)}$	Dim. Less	0.112	0.217	0.45	0.452	
$EF_{3(Liquid/solid)}$	kg N_2O-N kg	0.005	0.005	0.005	0.005	
$EF_{3(Solid\ storage)}$	kg N_2O-N kg	0.005	0.005	0.005	0.005	IPCC (2006, Table 10.21)
$EF_{3(deep\ bed.)}$	kg N_2O-N kg	0.01	0.01	0.01	0.01	
$N_{intake(T)}$	kg N hd^{-1} yr^{-1}	164	55.5	15.4	52.9	From protein content in feed
$N_{retention(T)}$	kg N hd^{-1} yr^{-1}	40.3	8.14	5.35	8.00	Equation 6.22 (*)
N_{milk}	kg N hd^{-1} yr^{-1}	40.2				Equation 6.22 (*)
$N_{weight\ gain}$	kg N hd^{-1} yr^{-1}	0.073	8.14	5.35	8.00	Equation 6.22 (*)
$N_{volatilization\text{-}MMS}$	kg N hd^{-1} yr^{-1}	6.26	2.48	0.973	4.37	Equation 6.22 (*)
EF_4	kg N_2O-N kg	0.01	0.01	0.01	0.01	IPCC (2006, Table 11.3)

The N inputs, outputs and emissions related to the British milk system are presented in Table 4.37. The N balance is calculated as N inputs minus the sum of N outputs and N emissions. When the N balance equals 0, it means all N is accounted for.

Table 4.37: N balances and emissions related to the British milk system. Unit: Kg N hd^{-1} yr^{-1}.

United Kingdom	Milk system			
	Dairy cow	Raising heifer calf	Raising bull calf	Raising bull
N inputs				
Feed	164	55.5	15.4	52.9
N outputs				
Milk	40.2			
Weight gain, live weight	0.073	8.14	5.35	8.0
Manure leaving storage	61.1	12.1	3.50	15.7
Manure excreted outdoor	55.7	32.7	5.48	24.6
N emissions				
Ammonia from stable	5.01	2.24	0.902	4.05
Ammonia from storage	1.25	0.246	0.071	0.321
N_2O-N_{direct}	0.408	0.125	0.045	0.203
N balance*	0	0	0	0

4.5 Summary of the LCI of cattle system

Summaries of LCI of the German, Danish, Swedish and British milk systems are presented in Table 4.38, Table 4.39, Table 4.40 and Table 4.41. The Brazilian beef system is presented in Table 4.42.

Table 4.38: LCI for the activities in the German milk system. The data represent one dairy cow during one year.

Germany Exchanges	Activity: Unit:	LCI data per dairy cow incl. offspring during one year			
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull
Output of products					
Determining product:					
Milk	kg	7,202			
Animals to raising	p		1.05	0.068	0.486
By-product:					
Meat, live weight	kg	148	74.2		197
Exported animals for raising, live weight	kg	1.97	3.22		
Material for treatment:					
Manure deposited outdoor	kg N	11.1	6.5		1
Manure land application, liquid/slurry	kg N	74.2	12.4		10.5
Manure land application, solid	kg N				
Manure land application, deep litter	kg N	19.9	12.9	0.618	7.05
Destruction of fallen cattle	kg	13.4	11.3	0.31	14.3
Input of products					
Wheat	kg	53.3	15.9	0.416	10.7
Corn	kg	228	68.0	1.78	45.6
Soybean meal	kg	423	126	3.31	84.8
Rapeseed cake/meal	kg	497	148	3.88	100
Molasses	kg	129	38.4	1.00	25.7
Palm kernel meal	kg	114	34.0	0.891	22.8
Wheat bran	kg	300	89.4	2.34	60.0
Malt sprouts	kg	110	32.7	0.857	22.0
Minerals, salt etc.	kg	27.7	8.25	0.216	5.54
Permanent grass	kg	717	214	5.60	144
Maize ensilage	kg	7,405	2,210	57.9	1,483
Rotation grass	kg	5,087	1,519	39.8	1,019
Lorry	tkm	376	112	2.94	75.3
Ship	tkm	6,829	2,039	53.4	1,368
Electricity	kWh	1,300			
Diesel	MJ	843	403	33.1	227
Capital goods (per cow)	p	2.60			
Services (per cow)	p	2.60			
Emissions					
Methane	kg CH_4	151	43.3	1.23	29.6
Dinitrogen monoxide (direct)	kg N_2O	0.994	0.352	0.013	0.222
Dinitrogen monoxide (indirect)	kg N_2O	0.154	0.065	0.003	0.039
Ammonia	kg NH_3	11.9	5.04	0.209	3.01

Table 4.39: LCI for the activities in the Danish milk system. The data represent one dairy cow during one year.

Denmark Exchanges	Activity: Unit:	LCI data per dairy cow incl. offspring during one year			
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull
Output of products					
Determining product:					
Milk	kg	8,704			
Animals to raising	p		0.960	0.082	0.290
By-product:					
Meat, live weight	kg	184	37.9		147
Exported animals for raising, live weight	kg	4.96		3.24	
Material for treatment:					
Manure deposited outdoor	kg N	6.37	12.5		
Manure land application, liquid/slurry	kg N	114	14.8	0.614	2.33
Manure land application, solid	kg N	2.35	0.499	0.072	0.065
Manure land application, deep litter	kg N	6.09	6.74	0.066	5.45
Destruction of fallen cattle	kg	35.5	16.3	2.41	9.95
Input of products					
Barley	kg	980	250	4.92	76
Corn	kg	49.2	12.6	0.247	3.80
Soybean meal	kg	346	88.3	1.74	26.8
Rapeseed cake/meal	kg	374	95.3	1.88	28.9
Sunflower meal	kg	293	74.7	1.47	22.6
Beet pulp, dried	kg	109	27.7	0.545	8.39
Molasses	kg	36.1	9.19	0.181	2.79
Palm oil	kg	28.0	7.15	0.141	2.17
Wheat bran	kg	34.1	8.69	0.171	2.63
DDGS	kg	5.70	1.45	0.029	0.440
Feed urea	kg	9.27	2.36	0.047	0.72
Minerals, salt etc.	kg	14.3	3.64	0.072	1.10
Permanent grass	kg	675	172	3.39	52.2
Maize ensilage	kg	6,257	1,595	31.4	484
Rotation grass	kg	8,728	2,226	43.9	674
Lorry	tkm	456	116	2.29	35.2
Ship	tkm	4,604	1,174	23.1	356
Electricity	kWh	1,300			
Diesel	MJ	995	296	39.6	140
Capital goods (per cow)	p	2.33			
Services (per cow)	p	2.33			
Emissions					
Methane	Kg CH_4	181	43.1	0.837	14.3
Dinitrogen monoxide (direct)	kg N_2O	1.09	0.251	0.007	0.12
Dinitrogen monoxide (indirect)	kg N_2O	0.143	0.035	0.001	0.011
Ammonia	kg NH_3	11.0	2.74	0.066	0.887

Table 4.40: LCI for the activities in the Swedish milk system. The data represent one dairy cow during one year.

Sweden Exchanges	**Activity: Unit:**	**LCI data per dairy cow incl. offspring during one year**			
		Dairy cow	**Raising heifer calf**	**Raising bull calf**	**Raising bull**
Output of products					
Determining product:					
Milk	kg	8,451			
Animals to raising	p		1.03	0.062	0.686
By-product:					
Meat, live weight	kg	164	36.4		207
Material for treatment:					
Manure deposited outdoor	kg N	29.9	16.9	0.323	12.2
Manure land application, liquid/slurry	kg N	77.3	4.50	0.086	3.24
Manure land application, solid	kg N	15.7	4.59	0.088	3.30
Manure land application, deep litter	kg N	1.56	5.32	0.102	3.83
Destruction of fallen cattle	kg	31.2	13.2	3.19	12.4
Input of products					
Barley	kg	463	117	2.71	98.0
Wheat	kg	151	38.2	0.885	32.0
Oat	kg	321	81.0	1.88	67.9
Corn	kg	7.86	1.98	0.046	1.66
Soybean meal	kg	330	83.3	1.93	69.8
Rapeseed cake/meal	kg	342	86.2	2.00	72.3
Beet pulp	kg	195	49.3	1.14	41.3
Molasses	kg	40.3	10.2	0.236	8.53
Palm oil	kg	109	27.5	0.637	23.0
Palm kernel meal	kg	104	26.3	0.610	22.1
Wheat bran	kg	110	27.8	0.643	23.3
Minerals, salt etc.	kg	70.7	17.8	0.413	14.9
Permanent grass	kg	4,299	1,084	25.1	909
Maize ensilage	kg	951	240	5.6	201
Rotation grass	kg	9,681	2,441	56.6	2,047
Lorry	tkm	449	113	2.6	95.0
Ship	tkm	7,197	1,815	42.0	1,522
Electricity	kWh	1,300			
Diesel	MJ	977	230	13.8	152
Capital goods (per cow)	p	2.78			
Services (per cow)	p	2.78			
Emissions					
Methane	kg CH_4	154	36.9	0.855	30.9
Dinitrogen monoxide (direct)	kg N_2O	0.811	0.177	0.003	0.128
Dinitrogen monoxide (indirect)	kg N_2O	0.101	0.030	0.001	0.022
Ammonia	kg NH_3	7.80	2.35	0.045	1.69

Table 4.41: LCI for the activities in the United Kingdom milk system. The data represent one dairy cow during one year.

United Kingdom Exchanges	Activity: Unit:	LCI data per dairy cow incl. offspring during one year			
		Dairy cow	Raising heifer calf	Raising bull calf	Raising bull
Output of products					
Determining product:					
Milk	kg	7,620			
Animals to raising	p		0.815	0.044	0.775
By-product:					
Meat, live weight	kg	116	88.1		239
Material for treatment:					
Manure deposited outdoor	kg N	50.2	21.9	0.188	14.8
Manure land application, liquid/slurry	kg N	43.9	2.65		
Manure land application, solid	kg N	4.76	0.290		
Manure land application, deep litter	kg N	12.5	6.90	0.155	12.2
Destruction of fallen cattle	kg	39.7	12.3	3.04	13.0
Input of products					
Barley	kg	755	219	2.68	226
Wheat	kg	457	133	1.62	137
Soybean meal	kg	96.6	28.1	0.343	28.9
Rapeseed cake/meal	kg	380	110	1.35	114
Sunflower meal	kg	75.9	22.0	0.270	22.7
Beet pulp, dried	kg	94.5	27.4	0.336	28.3
Minerals, salt etc.	kg	88.9	25.8	0.316	26.6
Permanent grass	kg	2,757	801	9.79	825
Maize ensilage	kg	3,290	956	11.7	984
Rotation grass	kg	9,300	2,701	33.0	2,782
Lorry	tkm	390	113	1.38	117
Lorry	tkm	1,168	339	4.15	349
Electricity	kWh	1,300			
Diesel	MJ	908	122	9.67	169
Capital goods (per cow)	p	2.63			
Services (per cow)	p	2.63			
Emissions					
Methane	kg CH_4	153	42.4	0.542	45.7
Dinitrogen monoxide (direct)	kg N_2O	0.641	0.160	0.003	0.247
Dinitrogen monoxide (indirect)	kg N_2O	0.098	0.032	0.001	0.053
Ammonia	kg NH_3	7.60	2.46	0.052	4.11

Table 4.42: LCI for the activities in the Brazilian beef system. The data represent 1 dairy cow during one year.

Brazil Exchanges	Activity: Unit:	LCI data per suckler cow incl. offspring during one year		
		Suckler cow	Raising heifer calf	Raising bull calf
Output of products				
Determining product:				
Meat, live weight	kg	63.5		
Animals to raising	p		0.90	0.90
By-product:				
Meat, live weight	kg		70.3	139
Exported animals for rasing, live weight	kg			
Material for treatment:				
Manure deposited outdoor	kg N	72.3	37.5	49.8
Destruction	kg	2.93	6.10	7.71
Input of products				
Minerals, salt etc.	kg	17.0	9.32	12.2
Permanent grass	kg	12,695	6,944	9,117
Lorry	tkm	3.41	1.86	2.45
Electricity	kWh	38.0		
Emissions				
Methane	Kg CH_4	50.6	27.7	36.3

4.6 Parameters relating to switch between modelling assumptions

The allocation factors used for switching between the four modelling assumptions are presented in Table 4.43.

Switch 1: Allocation is avoided by substitution. Consequently, milk production results in avoided production of e.g. cattle meat and fertilisers.

Switch 2: Co-products are modelled using allocation at the point of substitution. The allocation factors are obtained by combining the product amounts (Section 3.4 and 3.6) with the relevant product prices from Appendix C: Prices.

Switch 3 and 4: Co-products are modelled using allocation at the point of substitution or at other points as defined in PAS2050 and IDF. The allocation factors are obtained by combining the product amounts (Section 3.4 and 3.6) with the relevant product prices from Appendix C: Prices. However, the allocation factor between milk and meat for IDF is special, i.e. it is based on the supply of milk and meat and the following formula (IDF 2010, p 20):

Equation 4.7

$$\mathrm{af} = 1 - 5.7717 \cdot \frac{\mathrm{M_{meat}}}{\mathrm{M_{milk}}}$$

where:

- af is the allocation factor for milk
- M_{meat} is the sum of live weight of all animals sold including bull calves and culled mature animals
- M_{milk} is the sum of ECM sold milk

Table 4.43: Allocation factors used for allocation of products produced in the systems in Germany, Denmark, Sweden and United Kingdom. Unit: Fraction.

Country:	**DE**	**DK**	**SE**	**UK**
Switch 1: ISO 14040/44 consequential				
Determining product:				
Milk	1.00	1.00	1.00	1.00
Switch 2: Average/allocation				
Determining product:				
Milk	0.655	0.760	0.681	0.757
By-products at point of substitution:				
Cattle meat, live weight	0.282	0.179	0.263	0.173
Exported animals for raising, live weight	0.004	0.004		
N fert as N	0.025	0.025	0.028	0.032
P fert as P_2O_5	0.007	0.007	0.009	0.012
K fert as K_2O	0.02	0.02	0.017	0.023
Heat	0.000005	0.00001	0.00001	0.000002
Burning coal	0.0002	0.0003	0.0002	0.0003
Burning fuel oil	0.001	0.001	0.001	0.002
Switch 3: PAS2050				
Determining product:				
Milk	0.696	0.806	0.722	0.814
By-products at point of substitution:				
Cattle meat, live weight	0.300	0.189	0.278	0.186
Exported animals for raising, live weight	0.0037	0.004		
Switch 4: IDF				
Determining product:				
Milk	0.790	0.832	0.840	0.840
By-products:				
Cattle meat, live weight	0.206	0.163	0.160	0.160
Exported animals for raising, live weight	0.004	0.005		

5 The plant cultivation system

This chapter presents the inventory of the plan cultivation system including all crops/fourages and contries relating to milk production in Germany, Denmark, Sweden and United Kingdom.

5.1 Outputs and inputs of products

Outputs and inputs of barley cultivation are presented in Table 5.1. The yields are calculated by linear regression over the period 2003-2012 and data are obtained from FAOSTAT (2014). Yields for the specific year 2012 are not used because yields can vary considerable amongst years due to drought, diseases etc. Calculation of the other parameters is explained in the sections 'N-fertilisers', 'P-,K-fertilisers' and 'Other inputs'.

Table 5.1: Outputs and inputs of products. Barley cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Barley					
		DE	DK	SE	UK	UA	EU27
Output of products							
Determining product: Barley	kg	6,136	5,382	4,422	5,641	2,358	4,430
Material for treatment: Straw	kg		1,889	1,591			
Input of products							
N-fert: Ammonia	kg N		1.81			3.10	0.07
N-fert: Urea	kg N	28.7	0.30		20.1	4.25	15.9
N-fert: AN	kg N		2.41	3.40	50.6	12.5	14.6
N-fert: CAN	kg N	50.7	24.7	44.7	8.17	0.85	17.2
N-fert: AS	kg N	6.43	1.81		4.36	0.14	2.13
Manure	kg N	107	77.6	58.7	76.2	11.3	75.8
P fert: TSP	kg P_2O_5	6.31	3.88	0.78	10.2	2.32	5.18
K fert: KCl	kg K_2O	10.1	9.14	1.25	28.8	2.09	5.45
Pesticides	kg a.i.	0.509	0.51	0.509	0.51	0.509	0.509
Lorry	tkm	66.8	29.9	36.7	71.2	14.3	38.1
Diesel	MJ	3,046	3,046	3,046	3,046	3,046	3,046
Light fuel oil for drying	MJ	1.10	1.10	1.10	1.10	1.10	1.10
Land tenure, arable	kg C	6,500	7,000	5,600	5,500	5,000	7,000

Outputs and inputs of wheat cultivation are presented in Table 5.2.

Table 5.2: Outputs and inputs of products. Wheat cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Wheat				
		DE	DK	SE	UK	EU27
Output of products						
Determining product: Wheat	kg	7,428	7,118	5,860	7,407	5,389
Material for treatment: Straw	kg		3,594	2,993		
Input of products						
N-fert: Ammonia	kg N		2.58			0.082
N-fert: Urea	kg N	31.5	0.43		32.0	17.5
N-fert: AN	kg N		3.44	5.13	80.4	16.1
N-fert: CAN	kg N	55.8	35.2	67.4	13.0	19.0
N-fert: AS	kg N	7.07	2.58		6.92	2.34
Manure	kg N	118	111	88.7	121	83.4
P fert: TSP	kg P_2O_5	6.31	3.88	0.91	7.85	5.18
K fert: KCl	kg K_2O	16.9	15.3	1.14	20.0	9.13
Pesticides	kg a.i.	0.603	0.603	0.603	0.603	0.603
Lorry	tkm	75.2	41.8	54.7	94.3	42.7
Diesel	MJ	3,306	3,306	3,306	3,306	3,306
Light fuel oil for drying	MJ	1.10	1.10	1.10	1.10	1.10
Land tenure, arable	kg C	6,500	7,000	5,600	5,500	7,000

Outputs and inputs of oat, corn and soybean cultivation are presented in Table 5.3.

Table 5.3: Outputs and inputs of products. Oat, corn and soybean cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Oat				Corn	Soybean
		DE	DK	SE	UK	EU27	BR
Output of products							
Determining product: Oat/corn/soybean	kg	4,627	4,706	3,806	5,382	7,051	2,903
Material for treatment: Straw	kg		1,686	1,427			
Input of products							
N-fert: Ammonia	kg N		1.44			0.074	
N-fert: Urea	kg N	22.0	0.24		16.3	15.9	8.56
N-fert: AN	kg N		1.91	2.90	41.1	14.6	2.38
N-fert: CAN	kg N	38.9	19.6	38.1	6.62	17.2	0.416
N-fert: AS	kg N	4.93	1.44		3.53	2.13	2.01
Manure	kg N	82.3	61.6	50.1	61.8	75.8	4.79
P fert: TSP	kg P_2O_5	7.17	4.40	0.78	8.79	8.95	29.7
K fert: KCl	kg K_2O	12.0	10.8	1.14	22.5	7.36	51.3
Pesticides	kg a.i.	0.355	0.35	0.35	0.35	3.53	2.50
Lorry	tkm	55.2	26.5	31.4	57.9	44.4	59.0
Diesel	MJ	3,046	3,046	3,046	3,046	3,306	1,709
Light fuel oil for drying	MJ	1.10	1.10	1.10	1.10	1.10	1.10
Land tenure, arable	kg C	6,500	7,000	5,600	5,500	7,000	9,000

Outputs and inputs of rapeseed, sunflower, sugar beet and oil palm cultivation are presented in Table 5.4.

Table 5.4: Outputs and inputs of products. Rapeseed, sunflower, sugar beet and oil palm cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Rapeseed	Sunflower	Sugar beet				Oil palm
		EU27	FR	DE	DK	SE	UK	MY/ID
Output of products								
Determining product: Rapeseed/sunflower/sugar beet/oil palm	kg	3,028	2,459	70,922	63,855	59,094	66,812	17,260
Material for treatment: Straw	kg							
Input of products								
N-fert: Ammonia	kg N	0.084			1.77			
N-fert: Urea	kg N	18.0	5.33	27.7	0.30		16.5	151
N-fert: AN	kg N	16.5	10.0		2.37	4.13	41.5	10.8
N-fert: CAN	kg N	19.5	4.43	49.0	24.2	54.3	6.69	
N-fert: AS	kg N	2.42	0.269	6.22	1.77		3.57	
Manure	kg N	85.9	29.6	104	76.1	71.4	62.4	0.580
P fert: TSP	kg P_2O_5	7.54	3.68	12.6	7.75	2.08	7.22	35.5
K fert: KCl	kg K_2O	11.5	6.87	35.3	31.9	4.05	45.1	222
Pesticides	kg a.i.	0.270	0.270	2.74	2.74	2.74	2.74	2.60
Lorry	tkm	46.8	18.4	82.7	43.8	48.0	67.3	198
Diesel	MJ	3,195	3,306	8,581	8,581	8,581	8,581	1,710
Light fuel oil for drying	MJ	1.10	1.10					
Land tenure, arable	kg C	7,000	7,000	6,500	7,000	5,600	7,000	11,000

Outputs and inputs of oat, corn and soybean cultivation are presented in Table 5.5.

Table 5.5: Outputs and inputs of products. Permanent grass cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Permanent grass				
		DE	DK	SE	UK	BR
Output of products						
Determining product: Permanent grass	kg	6,000	11,628	9,302	9,136	9,585
Input of products						
N-fert: Ammonia	kg N		2.99			
N-fert: Urea	kg N	37.2	0.50		9.16	0.640
N-fert: AN	kg N		3.99	7.50	23.0	0.178
N-fert: CAN	kg N	65.8	40.9	98.5	3.71	0.0311
N-fert: AS	kg N	8.34	2.99		1.98	0.151
Manure	kg N	20.0	14.6	29.1	37.8	57.4
P fert: TSP	kg P_2O_5	3.73	1.41	1.69	2.51	
K fert: KCl	kg K_2O	18.8	10.2	8.31	6.44	
Pesticides	kg a.i.	0.095	0.095	0.0950	0.095	
Lorry	tkm	84.1	42.0	82.5	27.4	0.551
Diesel	MJ	557	557	557	557	32.3
Light fuel oil for drying	MJ					
Land tenure, arable	kg C	6,500	7,000	2,800	5,500	
Land tenure, intensive forest land	kg C			2,800		
Land tenure, rangeland	kg C					9,000

Outputs and inputs of rotation grass, incl. grass ensilage cultivation are presented in Table 5.6.

Table 5.6: Outputs and inputs of products. Rotations grass, incl. grass ensilage cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Rotation grass, incl. grass ensilage			
		DE	DK	SE	UK
Output of products					
Determining product: Rotation grass	kg	19,455	23,613	22,890	18,533
Input of products					
N-fert: Ammonia	kg N		10.4		
N-fert: Urea	kg N	54.7	1.73		15.7
N-fert: AN	kg N		13.8	5.94	39.4
N-fert: CAN	kg N	96.7	142	78.1	6.4
N-fert: AS	kg N	12.3	10.4		3.39
Manure	kg N	29.5	50.5	23.0	64.8
P fert: TSP	kg P_2O_5	12.9	7.93	2.10	7.85
K fert: KCl	kg K_2O	32.2	10.4	9.72	10.3
Pesticides	kg a.i.	0.0950	0.10	0.095	0.095
Lorry	tkm	133	146	67.5	50.3
Diesel	MJ	2,415	2,415	2,415	2,415
Land tenure, arable	kg C	6,500	7,000	5,600	5,500

Outputs and inputs of oat, corn and soybean cultivation are presented in Table 5.7.

Table 5.7: Outputs and inputs of products. Roughage, maize ensilage cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Roughage, maize ensilage			
		DE	DK	SE	UK
Output of products					
Determining product: Roughage	kg	29,507	35,813	28,463	28,139
Input of products					
N-fert: Ammonia	kg N		2.38		
N-fert: Urea	kg N	16.2	0.40		10.2
N-fert: AN	kg N		3.17	2.00	25.7
N-fert: CAN	kg N	28.7	32.5	26.3	4.15
N-fert: AS	kg N	3.64	2.38		2.21
Manure	kg N	60.8	102	34.5	38.7
P fert: TSP	kg P_2O_5	12.9	7.93	2.10	7.85
K fert: KCl	kg K_2O	32.2	29.1	9.72	10.3
Pesticides	kg a.i.	0.095	0.095	0.095	0.095
Lorry	tkm	57.7	48.6	26.7	37.0
Diesel	MJ	3,715	3,715	3,715	3,715
Land tenure, arable	kg C	6,500	7,000	5,600	5,500

N-fertilisers

The inputs of mineral fertiliser and manure are modelled as a top-down approach, where the total mineral fertiliser consumption and manure production in 2012 are distributed over the total area of fertilised agricultural land, while taking into account that the nitrogen demand of different crops differ. The procedure is the described below, using Germany as an example.

Germany

Firstly, the total amounts of nitrogen in mineral fertiliser and manure are estimated, see Table 5.8. According to IFA (2015), 1,647,800 tonnes of mineral fertiliser were consumed in Germany in 2012. The amount of nitrogen in manure excreted by livestock in Germany in 2012 is estimated by using the same procedure as described by Dalgaard and Schmidt (2012a, p. 56-57). However, data on nitrogen excretion from different animal types are updated with newer data representing the year 2012 (Mikkelsen 2014, pers. comm. 24 September 2014). The data from Mikkelsen (2014) are based on the same modelling procedure and data sources as published by Mikkelsen et al. (2014). The annual milk yield per cow was higher in Denmark compared to Germany, and the N excretion per cow will therefore also be higher in Denmark. Thus, it was decided to use German data on nitrogen excretion from the cattle sector (Haenel et al. 2014) instead of the data from Mikkelsen (2014).

Table 5.8: Fertiliser applied to fields in Germany 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser applied to fields	1,648
Total manure fertiliser	1,221
Total	**2,869**

The total amounts of fertiliser applied to fields are presented in Table 5.8. The share of manure excreted on pasture/rotation grass is 10.6% (Haenel et al. 2014).

Hereafter, data on crop areas (Table 5.9) are obtained from FAOSTAT (2014). The area named 'permanent grass' is the same as 'permanent meadows and pastures' from FAOSTAT (2014). Forage includes different kinds of silage and a category named 'Forage products'. The category 'Grain, mixed' from FAOSTAT (2014) has been assigned to 'Wheat' in Table 3.3. All vegetables and fruits are aggregated in the category 'Vegetable, fruits'. IFA et al. (2002) estimated the amount of nitrogen fertiliser (mineral fertiliser and manure) applied to the different crops in 1999/2000 in Germany. These data are used to distribute the nitrogen unevenly between the crops and thereby avoid the rough assumption, that all crops receive same amount of nitrogen fertilisers. It is assumed all the manure excreted on pasture is applied to the permanent grass.

Table 5.9: Agricultural areas and fertiliser application in Germany 2012. Sources: FAOSTAT (2014), IFA et al. (2002).

Agricultural crops	Agricultural area, ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	4,630,000	111	20
Rotation grass	1,648,440	164	29
Maize ensilage	1,489,473	49	61
Barley	1,683,000	86	107
Wheat	3,092,900	94	118
Oats	146,000	66	82
Corn	510,000	86	107
Rapeseed	1,306,200	97	122
Sugar beet	402,100	83	104
Rye	710,000	66	82
Triticale	371,400	94	118
Potatoes	238,300	80	100
Vegetable, fruits, nuts	417,091	94	118
Sum of above	**ha**	**1000 ton N**	**1000 ton N**
Area	16,644,904		
Fertiliser		1,648	1,221
Statistical data: Table 5.8		1,648	1,221

Finally, the mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.10.

Table 5.10: Distribution of N between different types of mineral nitrogen fertiliser types in Germany 2012. Based on IFA (2014).

Fertiliser types	Germany
N-fert: Ammonia	0%
N-fert: Urea	33.4%
N-fert: AN	0%
N-fert: CAN	59.1%
N-fert: AS	7.49%
Total	**100%**

Denmark

The amount of mineral fertiliser applied in Denmark and total amount of manure (Table 5.11), are delivered from IFA (2015) and Mikkelsen et al. (2014), respectively. Based on the average grazing times for different types of livestock (Mikkelsen et al. 2014) it was estimated that 10.6% of manure is excreted on pasture. One modification is included: for suckler cows the grazing time of 112 days is used instead of 224 days.

Table 5.11: Fertiliser applied to fields in Denmark 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser	194
Manure fertiliser	225
Total	**419**

Crops cultivated in Denmark are divided into groups according to Plantedirektoratet (2011) and the same source provides rates of nitrogen fertiliser applied (Table 5.12). The areas of agricultural production are extracted from FAOSTAT (2004).

Table 5.12: Agricultural areas and fertiliser application in Denmark 2012. Sources: FAOSTAT (2014), Plantedirektoratet (2011)

Agricultural crops	Agricultural area, ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	200,000	51	15
Rotation grass	600,142	178	50
Maize ensilage	275,058	41	102
Barley	723,400	31	78
Wheat	614,100	44	111
Oats	58,400	25	62
Corn	12,900	41	102
Rapeseed	129,100	51	128
Sugar beet	41,000	30	76
Rye	64,600	32	81
Triticale	22,000	39	97
Potatoes	39,500	41	101
Cereal grains	7,900	38	94
Vegetable, fruits, nuts	27,923	50	124
Totals	**ha**	**1000 ton N**	**1000 ton N**
Sum of above	2,816,023	194	225
Statistical data: Table 5.11		194	225

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.13.

Table 5.13: Distribution of N between different types of mineral nitrogen fertiliser types in Denmark 2012. Based on IFA (2014).

Fertiliser types	Denmark
N-fert: Ammonia	5.83%
N-fert: Urea	0.971%
N-fert: AN	7.77%
N-fert: CAN	79.6%
N-fert: AS	5.83%
Total	**100%**

Sweden

The amount of mineral fertiliser applied in Sweden and total amount of manure (Table 5.14), are from IFA (2015) and Al-Hanbali (2014), respectively. Manure excretion from dairy cows is calculated based on the trend presented in Al-Hanbali (2014, Table 6.13), applying the milk yield of 8,722 kg/year/head. Rates of manure for other animals are provided in above publication. Based on the average grazing times for different types of livestock (Al-Hanbali 2014) it was estimated that 31.8% of manure is excreted on pasture.

Table 5.14: Fertiliser applied to fields in Sweden 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser	162
Manure fertiliser	125
Total	**287**

Crops cultivated in Sweden are divided into groups according to SCB (2014) and the same source provides rates of nitrogen fertiliser applied. However, the amount of nitrogen applied to oat ensilage is from SP Foder (2015, Oat whole crop ensilage (mellensköрd). The areas of agricultural production are extracted from FAOSTAT (2014), see Table 5.15. The area reported there as 'pumpkin for fodder' is equivalent to the sum of areas of 'green fodder and 'utilized ley for hay and pasture' (SCB 2015) and is, therefore, used in this study as the area of rotation grass and roughage.

Table 5.15: Agricultural areas and fertiliser application in Sweden 2012. Sources: FAOSTAT (2014), SCB (2014).

Agricultural crops	Agricultural area, ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	88,120	106	29
Extensive permanent grass, not	352,480	25	7
Rotation grass	695,348	84	23
Oat ensilage	514,652	28	35
Barley	370,000	48	59
Wheat	367,000	73	89
Oats	191,400	41	50
Corn	0		
Rapeseed	107,250	82	100
Sugar beet	39,000	58	71
Rye	22,000	53	65
Triticale	23,700	58	71
Potatoes	24,720	70	85
Cereal grains	17,900	51	62
Vegetable, fruits, nuts	54,995	45	55
Totals	**ha**	**1000 ton N**	**1000 ton N**
Sum of above	2,868,565	162	125
Statistical data: Table 5.11		162	125

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.16.

Table 5.16: Distribution of N between different types of mineral nitrogen fertiliser types in Sweden 2012. Based on IFA (2014).

Fertiliser types	Sweden
N-fert: Ammonia	0%
N-fert: Urea	0%
N-fert: AN	7.07%
N-fert: CAN	92.9%
N-fert: AS	0%
Total	**100%**

United Kingdom

The amount of mineral fertiliser applied in United Kingdom and total amount of manure (Table 5.17), are from FAOSTAT (2014) and Webb et al. (2014a), respectively. Based on the distribution of manure from different types of livestock (Webb et al. 2014a) it was estimated that 20.3% of manure is excreted on pasture.

Table 5.17: Fertiliser applied to fields in United Kingdom 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser	995
Manure fertiliser	950
Total	**1,945**

Crops cultivated in United Kingdom are divided into groups according to Defra et al. (2013) and the same source provides rates of nitrogen fertiliser applied (Table 5.18). The areas of agricultural production are extracted from FAOSTAT (2014). The area reported there as 'pumpkin for fodder' corresponds to the area of 'temporary grass, under 5 years old' (Defra 2012) and is, therefore, distributed in this study between the areas of rotation grass and roughage.

Table 5.18: Agricultural areas and fertiliser application in United Kingdom 2012. Sources: FAOSTAT (2014), Defra et al. (2013)

Agricultural crops	Agricultural area, ha	Mineral fertiliser kg N/ha	Manure, kgN/ha
Permanent grass	4,369,600	38	38
Extensive permanent grass, not used for dairy	6,554,400	34	34
Rotation grass	1,357,000	65	65
Maize ensilage	51,000	42	39
Barley	1,002,000	83	76
Wheat	1,992,000	132	121
Oats	122,000	68	62
Rapeseed	756,000	134	122
Sugar beet	120,000	68	62
Rye	6,000	36	33
Triticale	14,000	36	33
Potatoes	149,000	86	78
Cereal grains	5,000	108	99
Vegetable, fruits, nuts	440,157	80	73
Sum of above	**ha**	**1000 ton N**	**1000 ton N**
Area	16,938,157		
Fertiliser		995	950
Statistical data: Table 5.17		995	950

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.19.

Table 5.19: Distribution of N between different types of mineral nitrogen fertiliser types in United Kingdom 2012. Based on IFA (2014).

Fertiliser types	United Kingdom
N-fert: Ammonia	0%
N-fert: Urea	24.2%
N-fert: AN	60.8%
N-fert: CAN	9.80%
N-fert: AS	5.23%
Total	**100%**

Brazil

The amount of mineral fertiliser applied in Brazil is delivered from FAOSTAT (2014), as presented in Table 5.20. The starting point for calculating the amount of manure is the values from Mikkelsen (2014, pers. comm. 24 September 2014) and Mikkelsen et al. (2014) as described in the section about Germany presented above. However, it is taking into account that the amount of manure per animal is different in Brazil due to completely different animal races and farming systems. This is carried out by using data from IPCC (2006). IPCC (2006, Table 10.19) provides region and livestock specific default values for nitrogen excretion rates per 1,000 kg animal per year. For example 'Other cattle', which includes all cattle except dairy cows, excretes 0.33 kg nitrogen per 1,000 kg animal per day in Western Europe and 0.36 in Latin America (IPCC 2006, Table 10.19). The weight per animal in the different regions is obtained from IPCC (2006, Table 10.A4-10A9). The weight of 'Other cattle' is lower in Latin America than in Western Europe, and therefore the nitrogen excretion per animal ('Other cattle') per year becomes higher in Western Europe (51 kg nitrogen per animal per year) than in Latin America (40 kg nitrogen per animal per year). In conclusion the nitrogen excretion is 22% lower for 'Other cattle' in Brazil, than in Western Europe. The nitrogen excretions for dairy cows in Western Europe and Latin America are calculated following the same procedure, and it appears that the excretion is 33% lower in Latin America compared to Western Europe. It is assumed that the distribution of cattle between the categories 'Dairy cows' and 'Other cattle' is 50/50 for all regions. This assumption is made because the number of animals derived from FAOSTAT (2014) only includes one cattle category. Likewise, it is assumed that the distribution between 'Swine, market' and 'Swine, breeding' is 50/50.

Using the procedure described above, gives the following values for nitrogen excretion per animal per year in Brazil: Cattle (55.2); pigs (4.38), poultry (0.982); horses (100) and sheep (9.01).

Table 5.20: Fertiliser applied to fields in Brazil 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser applied to fields	4,251
Manure fertiliser applied to fields	1,398
Manure excreted on pasture	11,315
Total	**16,964**

Manure excreted on pasture is calculated based on the assumption that in Brazil the entire fraction of cattle and horse manure is excreted outdoors. That corresponds to 88.6% of total manure excreted in 2012 and the remaining 11.4% is applied to fields.

Comparing to Germany, different categories of agricultural crops and fertiliser amounts (Table 5.21) had to be adapted and they are based on FAO (2004). The publication does not include all crops cultivated in Brazil, including two, relevant for the study: permanent grass and forage. Therefore, the following assumptions are made:

- The current application of mineral fertiliser on permanent grass is set at a level of 1 kg N/ha and permanent grass is excluded from the fertiliser distribution key.
- The application of mineral fertiliser on forage in 2004 is assumed to be 20 kg N/ha.
- Crops, which were not distributed among categories listed in FAO (2004), are grouped as 'Others'. The amount of fertiliser applied is assumed to be the average of fertiliser applications for all the other categories.
- The agricultural areas are provided by FAOSTAT (2014) with the exception for the forage, which is calculated as difference between the area of arable land reported in FAOSTAT (2014) and the sum of harvest areas of all the crops listed by the same source.

Table 5.21: Agricultural areas and fertiliser application in Brazil 2012. Sources: FAOSTAT (2014). FAO (2004).

Agricultural crops	Agricultural area, ha	Fertiliser applied in 2004, kg N/ha	Fertiliser distribution key	Fertiliser (mineral + manure), kg N/ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	196,000,000	0	0%	58.7	1.00	57.7
Roughage	11,326,533	20.0	9.33%	44.9	33.4	11.5
Cotton	1,381,919	83.0	4.73%	187	139	47.8
Rice	2,413,288	27.0	2.68%	60.7	45.1	15.6
Potatoes	135,970	121	0.678%	272	202	69.7
Coffee	2,120,080	114	10.0%	256	190	65.7
Sugar cane	9,705,388	55.0	22.0%	124	91.9	31.7
Beans	2,730,454	8.00	0.900%	18.0	13.4	4.61
Citrus	833,073	55.0	1.89%	124	91.9	31.7
Maize	14,198,496	40.0	23.4%	89.9	66.8	23.0
Soybeans	24,975,258	8.00	8.23%	18.0	13.4	4.61
Wheat	1,912,711	12.0	0.946%	27.0	20.0	6.91
Barley	102,749	12.0	0.0508%	27.0	20.0	6.91
Other crops	983,982	43.0	1.74%	96.6	71.8	24.8
Others	6,785,099	48.2	13.5%	108	80.5	27.8
Total (excl. perm. grass)	**79,605,000**		**100%**			

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.22.

Table 5.22: Distribution of N between different types of mineral nitrogen fertiliser types in Brazil 2012. Based on IFA (2014).

Fertiliser types	Brazil
N-fert: Ammonia	0%
N-fert: Urea	64.0%
N-fert: AN	17.8%
N-fert: CAN	3.11%
N-fert: AS	15.1%
Total	**100%**

European Union

The amount of mineral fertiliser applied in European Union (Table 5.23) is delivered from FAOSTAT (2014) and the amount of manure is calculated according to the procedure described for Germany.

Table 5.23: Fertiliser applied to fields in European Union 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser applied to fields	10,776
Manure fertiliser applied to fields	9,432
Manure excreted on pasture	1,118
Total	**21,326**

To calculate the inputs of mineral fertiliser and manure (Table 5.24) two important assumptions were made:

- The categories of agricultural crops with corresponding rates of fertiliser applied are the same like in case of Germany.
- German share of manure excreted on pasture is used.

The method of calculating the N excretion was crosschecked with Velthof et al. (2014), who estimated the total N excretion from livestock in European Union for years 2000-2008. The number reported for 2008 is acceptably close to the value calculated in this study: 10 Mt of N (2008) comparing to 10.55 Mt of N (2012). Given that in period 2000-2008 the value was changing (both increasing and decreasing) it can be proved that our methodology is correct.

Table 5.24: Agricultural areas and fertiliser application in European Union 2012. Sources: FAOSTAT (2014), IFA et al. (2002).

Agricultural crops	Agricultural area, ha	Fertiliser applied in 1999/2000, kg N/ha	Fertiliser distribution key	Fertiliser (mineral + manure), kg N/ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	66,488,790	51.0	16.6%	53.2	36.4	16.8
Roughage	34,428,136	150	25.3%	156	73.5	83.0
Wheat	25,471,901	165	20.6%	172	80.9	91.3
Barley	12,498,037	150	9.17%	156	73.5	83.0
Rapeseed	6,203,291	170	5.16%	177	83.3	94.0
Rye	2,414,890	115	1.36%	120	56.4	63.6
Maize	9,802,412	85.0	4.08%	88.7	41.7	47.0
Sugar beet	1,659,991	145	1.18%	151	71.1	80.2
Triticale	2,431,885	165	1.96%	172	80.9	91.3
Potatoes	1,818,561	140	1.25%	146	68.6	77.4
Oats	2,680,550	115	1.51%	120	56.4	63.6
Sunflower seed	4,298,331	50.0	1.05%	52.2	24.5	27.7
Vegetables, fruits	19,349,468	115	10.9%	120	56.4	63.6
Total	**189,546,243**		**100%**			

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.25.

Table 5.25: Distribution of N between different types of mineral nitrogen fertiliser types in European Union 2012. Based on IFA (2014).

Fertiliser types	European Union
N-fert: Ammonia	0.149%
N-fert: Urea	31.8%
N-fert: AN	29.2%
N-fert: CAN	34.5%
N-fert: AS	4.27%
Total	**100%**

Ukraine

The amount of mineral fertiliser applied in Ukraine (Table 5.26) is delivered from FAOSTAT (2014) and the amount of manure is calculated according to the procedure described for Brazil, which means the nitrogen excretion rates per animal per year are adopted using the values from IPCC (2006, Table 10.A4-10A9) on nitrogen excretion. Data representing Eastern Europe are applied.

The following values for nitrogen excretion per animal per year in Ukraine are obtained: cattle (60.2); pigs (8.38), poultry (1.82); horses (65.2) and sheep (6.93).

Table 5.26: Fertiliser applied to fields in Ukraine 2012.

	1000 tonnes nitrogen
Mineral fertiliser applied to fields	928
Manure fertiliser applied to fields	466
Manure excreted on pasture	115
Total	**1,510**

Again, assumptions about grouping the crops and distributing the manure (Table 5.27) had to be made:

- The categories used for previously described countries do not cover all crops cultivated in Ukraine. Therefore, the crops are divided into groups with attributed rates of fertiliser according to methodology described in Schmidt et al. (2012). Since the publication does not provide specific values for Ukraine, in this project we assume that the rates of fertiliser applied in 2007 were equal to the Polish ones.
- Half of the manure from cattle and horses is assumed to be excreted outdoors. That gives the share of manure excreted on pasture of approx. 19.8%.

Table 5.27: Agricultural areas and fertiliser application in Ukraine 2012. Sources: FAOSTAT (2014), IFA et al. (2002).

Agricultural crops	Agricultural area, ha	Fertiliser applied in 2007, kg N/ha	Fertiliser distribution key	Fertiliser (mineral + manure), kg N/ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	7,885,000	40.0	12.4%	23.8	9.21	14.6
Roughage	4,068,500	97.0	15.6%	57.7	37.4	20.4
Paddy rice	25,800	73.0	0.0743%	43.4	28.1	15.3
Wheat	5,629,700	74.0	16.4%	44.0	28.5	15.5
Cereal grains nec	6,875,500	54.0	14.6%	32.1	20.8	11.3
Vegetables, fruits	2,952,475	74.0	8.61%	44.0	28.5	15.5
Oil seeds	5,695,700	102	22.9%	60.7	39.3	21.4
Sugar beet	448,900	132	2.34%	78.6	50.9	27.7
Plant-based fibers	1,315	95.0	0.00%	56.5	36.6	19.9
Barley	3,293,000	54.0	7.01%	32.1	20.8	11.3
Total	**36,875,890**		**100%**			

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.28.

Table 5.28: Distribution of N between different types of mineral nitrogen fertiliser types in Ukraine 2012. Based on IFA (2014).

Fertiliser types	Ukraine
N-fert: Ammonia	14.9%
N-fert: Urea	20.4%
N-fert: AN	59.9%
N-fert: CAN	4.09%
N-fert: AS	0.683%
Total	100%

Russian Federation

The amount of mineral fertiliser applied in Russian Federation (Table 5.29) is delivered from FAOSTAT (2014) and the amount of manure is calculated according to the procedure described for Brazil, which means the nitrogen excretion rates per animal per year are adopted using the values from IPCC (2006, Table 10.9, Table 10.A4-10A9) on nitrogen excretion. Data representing Eastern Europe are applied and therefore the excretion rates per animal are the same as those used for Ukraine.

Table 5.29: Fertiliser applied to fields in Russian Federation 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser applied to fields	1,180
Manure fertiliser applied to fields	1,517
Manure excreted on pasture	544
Total	**3,241**

Like in case of Ukraine, the categories of agricultural crops and the rates of fertiliser applied (Table 5.30) are calculated with the method described in Schmidt et al. (2012). One modification is introduced: we assume that 30 kg N/ha was applied for permanent grass in 2007. Based on the assumption that half of cattle and horse manure is excreted outdoors, the share of manure excreted on pasture reaches 26.4%.

Table 5.30: Agricultural areas and fertiliser application in Russia 2012. Sources: FAOSTAT (2014), IFA et al. (2002).

Agricultural crops	Agricultural area, ha	Fertiliser applied in 2007, kg N/ha	Fertiliser distribution key	Fertiliser (mineral + manure), kg N/ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	93,000,000	30.0	40.6%	14.1	8.30	5.85
Roughage	17,250,100	5.00	1.26%	2.36	0.500	1.86
Paddy rice	191,600	73.0	0.204%	34.4	7.30	27.1
Wheat	21,277,900	74.0	22.9%	34.9	7.40	27.5
Cereal grains nec	7,877,500	54.0	6.19%	25.5	5.40	20.1
Vegetables, fruits	6,716,608	74.0	7.23%	34.9	7.40	27.5
Oil seeds	7,539,400	102	11.2%	48.1	10.2	37.9
Sugar beet	1,102,000	132	2.12%	62.2	13.2	49.0
Plant-based fibers	50,200	95.0	0.0694%	44.8	9.50	35.3
Barley	7,641,100	74.0	8.23%	34.9	7.40	27.5
Total	**162,646,408**		**100%**			

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.31.

Table 5.31: Distribution of N between different types of mineral nitrogen fertiliser types in Russia 2012. Based on IFA (2014).

Fertiliser types	Russian Federation
N-fert: Ammonia	0%
N-fert: Urea	4.52%
N-fert: AN	89.7%
N-fert: CAN	1.17%
N-fert: AS	4.60%
Total	**100%**

France

The amount of mineral fertiliser applied in France (Table 5.32) is delivered from FAOSTAT (2014) and the amount of manure is calculated according to the procedure described for Germany.

Table 5.32: Fertiliser applied to fields in France 2012.

Fertiliser	1000 tonnes nitrogen
Mineral fertiliser applied to fields	1,915
Manure fertiliser applied to fields	1,696
Manure excreted on pasture	201
Total	**3,812**

To calculate the inputs of mineral fertiliser and manure (Table 5.33) two important assumptions were made:

- The categories of agricultural crops with corresponding rates of fertiliser used for France are based on the data reported for Germany.
- The share of manure excreted on pasture is assumed to be the same as in Germany.

Table 5.33: Agricultural areas and fertiliser application in France 2012. Sources: FAOSTAT (2014), IFA et al. (2002).

Agricultural crops	Agricultural area, ha	Fertiliser applied in 1999/2000, kg N/ha	Fertiliser distribution key	Fertiliser (mineral + manure), kg N/ha	Mineral fertiliser, kg N/ha	Manure, kg N/ha
Permanent grass	9,546,200	51.0	15.4%	61.5	40.4	21.1
Roughage	4,776,647	150	22.7%	181	85.8	95.2
Wheat	5,468,868	165	28.5%	199	94.3	105
Barley	1,684,000	150	7.99%	181	85.8	95.2
Rapeseed	1,607,186	170	8.64%	205	97.2	108
Rye	31,546	115	0.115%	139	65.7	72.9
Maize	1,739,051	85.0	4.68%	103	48.6	53.9
Sugar beet	389,558	145	1.79%	175	82.9	92.0
Triticale	415,719	165	2.17%	199	94.3	105
Potatoes	154,229	140	0.683%	169	80.0	88.8
Oats	82,794	115	0.301%	139	65.7	72.9
Sunflower seed	679,974	50.0	1.08%	60.3	28.6	31.7
Vegetables, fruits	1,439,691	115	5.24%	139	65.7	72.9
Others	179,275	124	0.705%	150	71.1	78.9
Total	**28,194,738**		**100%**			

The mineral fertiliser is distributed between the different types of mineral nitrogen fertiliser types according to IFA (2014), as presented in Table 5.34.

Table 5.34: Distribution of N between different types of mineral nitrogen fertiliser types in France 2012. Based on IFA (2014).

Fertiliser types	France
N-fert: Ammonia	0%
N-fert: Urea	26.5%
N-fert: AN	50.0%
N-fert: CAN	22.1%
N-fert: AS	1.34%
Total	**100%**

Malaysia/Indonesia

A different approach is used to determine the fertiliser use for oil palm cultivation in Malaysia/Indonesia. Since specific data are available (Schmidt 2015) we introduce them directly into the model. The summary of fertiliser input is presented in Table 5.35.

Table 5.35: Application of N fertilisers for oil palm cultivation in Malaysia/Indonesia 2012. Based on Schmidt (2015).

Fertiliser	Oil palm cultivation, MY/ID
kg N mineral fertiliser, per ha	161.8
kg N manure, per ha	0.580
Total	**162.4**

P-, K-fertilisers

The top-down approach is also used to determine the rates of mineral phosphorus and potassium fertilisers (Table 5.36). The important modification is that the distribution key is calculated based on the Danish norms of fertiliser application (Plantedirektoratet 2011, Table 1). This rule applies for all the countries except for Brazil, where fertiliser application is based on values from FAO (2004). It is assumed that no P- and K-fertiliser is applied on permanent grass and roughage in Brazil. Like in case of N-fertiliser, the procedure is not used for Malaysia/Indonesia, because reliable data about fertiliser use for oil palm cultivation are already available.

Table 5.36: Application of mineral P- and K-fertilisers for selected crops in 2012.

Agricultural crops	Country	Fertiliser, kg P/ha	Fertiliser, kg K/ha
Permanent grass	DE	3.72	18.8
	DK	2.26	16.6
	SE	3.40	22.4
	UK	2.72	7.27
	BR	0	0
Rotation grass, incl. grass ensilage	DE	12.9	32.2
	DK	7.83	28.4
	SE	0.426	1.19
	UK	7.55	9.69
Roughage, maize ensilage	DE	12.9	32.2
	DK	7.83	28.4
	SE	0.426	1.19
	UK	7.55	9.69
	BR	0	0
Barley cultivation	DE	6.30	10.1
	DK	3.83	8.90
	SE	1.57	3.36
	UK	9.80	27.1
	UA	2.32	2.09
	EU27	5.18	5.45
Wheat cultivation	DE	6.30	16.9
	DK	3.83	14.9
	SE	1.83	3.08
	UK	7.55	18.8
	EU27	5.18	9.13
Oat cultivation	DE	7.16	12.0
	DK	4.35	10.6
	SE	1.57	3.08
	UK	8.45	21.2
Corn cultivation	EU27	8.95	7.36
Soybean cultivation	BR	33.8	56.7
Rapeseed cultivation	EU27	7.54	11.5
Sunflower cultivation	FR	3.68	6.87
Sugar beet cultivation	DE	12.6	35.3
	DK	7.66	31.1
	SE	4.18	10.9
	UK	6.94	42.4
Oil palm cultivation	MY/ID	35.5	222

The amount of organic P and K is calculated by multiplying the amount of applied N manure with the P and K content per unit N in manure. The P-N and K-N ratios for different types of manure are obtained from Poulsen et al. (2001).

Other inputs

The inputs of pesticides, transport, diesel, light fuel oil, capital goods and services are presented in section 0 (Table 5.49 to Table 5.55).

Utilisation of crop residues

These data have been modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

5.2 Emissions

Barley

The parameters used for calculation of emissions from cultivation of barley are presented in Table 5.37.

Table 5.37: Parameters used for calculation of emissions from cultivation of barley. (*): Schmidt and Dalgaard (2012). (**): IPCC (2006).

Parameter	Crop: Country: Unit:	Barley						Source
		DE	DK	SE	UK	UA	EU27	
$N_2O\text{-}N_{direct}$	kg N_2O–N ha^{-1} yr^{-1}	2.44	1.50	1.41	2.13	1.69	0.579	Equation 7.3(*)
$N_2O\text{-}N_{indirect}$	kg N_2O–N ha^{-1} yr^{-1}	0.850	0.523	0.483	0.714	0.582	0.174	Equation 7.5(*)
$N_2O\text{-}N_{N\ input}$	kg N_2O–N ha^{-1} yr^{-1}	2.44	1.50	1.41	2.13	1.69	0.579	Equation 7.3(*)
$N_2O\text{-}N_{OS}$	kg N_2O–N ha^{-1} yr^{-1}	0.376	0.15	0.152	0.224	0.128	0.024	Equation 7.3(*)
$N_2O\text{-}N_{PRP}$	kg N_2O–N ha^{-1} yr^{-1}							Equation 7.3(*)
F_{SN}	kg N ha^{-1} yr^{-1}	85.8	31.1	48.1	83.3	49.9	20.8	Table 5.1
F_{ON}	kg N ha^{-1} yr^{-1}	107	77.6	58.7	76.2	75.8	11.3	Table 5.1
F_{CR}	kg N ha^{-1} yr^{-1}	50.8	41.1	34.4	53.3	43.1	25.7	Equation 7.3(*)
Crop	kg DM ha^{-1} yr^{-1}	5,216	4,575	3,759	4,795	3,766	2,004	Table 11.2 (**)
Slope	Dim. less	0.980	0.980	0.980	0.980	0.980	0.980	Table 11.2 (**)
Intercept	Dim. less	0.590	0.590	0.590	0.590	0.590	0.590	Table 11.2 (**)
AG_{DM}	kg dm ha^{-1} yr^{-1}	5,701	5,073	4,273	5,289	4,280	2,554	Table 11.2 (**)
N_{AG}	kg N kg dm^{-1}	0.0070	0.007	0.007	0.007	0.0070	0.0070	Table 11.2 (**)
$Frac_{Remove}$	kg N kg crop-N^{-1}	0.166	0.284	0.291				See text
$R_{BG\text{-}BIO}$	kg dm kg dm^{-1}	0.220	0.220	0.220	0.220	0.220	0.220	Table 11.2 (**)
N_{BG}	kg N kg dm^{-1}	0.0140	0.014	0.014	0.014	0.0140	0.0140	Table 11.2 (**)
F_{SOM}	kg N yr^{-1}							See text
F_{OS}	ha	0.05	0.019	0.02	0.028	0.02	0.00	See text
F_{PRP}	kg N yr^{-1}							No grazing
EF_1	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	Table 11.1 (**)
EF_2	kg N_2O–N ha^{-1} yr^{-1}	8.00	8.00	8.00	8.00	8.00	8.00	Table 11.1 (**)
EF_{3PRP}	kg N_2O–N kg N^{-1}	0.02	0.02	0.02	0.02	0.02	0.02	Table 11.1 (**)
$Frac_{GASF}$	kg N kg N^{-1}	0.1	0.1	0.1	0.1	0.1	0.1	Table 11.3 (**)
$Frac_{GASM}$	kg N kg N^{-1}	0.2	0.2	0.2	0.2	0.2	0.2	Table 11.3 (**)
$Frac_{LEACH}$	kg N kg N^{-1}	0.3	0.3	0.3	0.3	0.3	0.3	Table 11.3 (**)
EF_4	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	Table 11.3 (**)
EF_5	kg N_2O–N kg N^{-1}	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	Table 11.3 (**)

F_{SOM} is assumed to be $F_{SOM} = 0$. This is in line with the assumption for changes of carbon on mineral soils: Change of carbon content in mineral soils is not included because it is argued that the changes only occur in a limited period after establishment of a certain crop.

The N inputs, outputs and emissions related to barley cultivation are presented Table 5.38. $N_{surplus}$ equals the sum of the N emissions, and the N balance is calculated as N surplus minus N emissions. When the N balance equals 0, it means all N is accounted for.

Table 5.38: N balances and emissions related to barley cultivation. (*): Schmidt and Dalgaard (2012). Unit: kg N ha^{-1} yr^{-1}.

Parameter	Barley						Source
	DE	DK	SE	UK	UA	EU27	
N inputs							
N-fert: Ammonia		1.81			3.10	0.074	Table 5.1
N-fert: Urea	28.7	0.30		20.1	4.25	15.9	Table 5.1
N-fert: AN		2.41	3.40	50.6	12.5	14.6	Table 5.1
N-fert: CAN	50.7	24.7	44.7	8.17	0.850	17.2	Table 5.1
N-fert: AS	6.43	1.81		4.36	0.142	2.13	Table 5.1
Manure	107	77.6	58.7	76.2	11.3	75.8	Table 5.1
Crop residues left in field	50.8	41.1	34.4	53.3	25.7	43.1	Table 5.1
Total N_{input}	**244**	**150**	**141**	**213**	**57.9**	**169**	Equation 7.1(*)
N outputs							
Harvested crop	90.1	79.1	64.9	82.9	34.6	65.1	Table 5.1
Crop residues removed	15.0	22.5	18.9				Table 5.1
Total N_{output}	**105**	**102**	**83.9**	**82.9**	**34.6**	**65.1**	Equation 7.1(*)
N inputs - N outputs							
$N_{surplus}$	139	48	130	126	23.2	104	Equation 7.1(*)
N emissions							
NH_3-N	25.5	15.8	14.1	20.0	3.70	17.1	Section 7.4 (*)
NO_x-N	4.51	2.80	2.48	3.53	0.652	3.02	Section 7.4 (*)
N_2O-N_{direct}	2.82	1.65	1.56	2.35	0.603	1.82	Equation 7.3(*)
N_2-N	32.8	-17.0	-3.17	40.2	0.934	31.2	Section 7.4 (*)
NO_3-N	73.2	44.9	42.3	63.8	17.4	50.7	Section 7.4 (*)
N balance	0	0	0	0	0	0	See text

Wheat

The parameters used for calculation of emissions from cultivation of wheat are presented in Table 5.39.

Table 5.39: Parameters used for calculation of emissions from cultivation of wheat. (*): Schmidt and Dalgaard (2012). (**): IPCC (2006).

Parameter	Crop: Country: Unit:	Wheat DE	DK	SE	UK	EU27	Source
$N_2O\text{-}N_{direct}$	kg N_2O–N ha^{-1} yr^{-1}	2.86	2.15	2.11	3.35	1.99	Equation 7.3(*)
$N_2O\text{-}N_{indirect}$	kg N_2O–N ha^{-1} yr^{-1}	0.975	0.748	0.724	1.13	0.670	Equation 7.5(*)
$N_2O\text{-}N_{N\ input}$	kg N_2O–N ha^{-1} yr^{-1}	2.86	2.15	2.11	3.35	1.99	Equation 7.3(*)
$N_2O\text{-}N_{OS}$	kg N_2O–N ha^{-1} yr^{-1}	0.376	0.152	0.152	0.224	0.128	Equation 7.3(*)
$N_2O\text{-}N_{PRP}$	kg N_2O–N ha^{-1} yr^{-1}						Equation 7.3(*)
F_{SN}	kg N ha^{-1} yr^{-1}	94.4	44.2	72.6	132	54.9	Table 5.2
F_{ON}	kg N ha^{-1} yr^{-1}	118	111	88.7	121	83.4	Table 5.2
F_{CR}	kg N ha^{-1} yr^{-1}	74.0	59.7	49.6	81.8	60.7	Equation 7.3(*)
Crop	kg DM ha^{-1} yr^{-1}	6,314	6,050	4,981	6,296	4,581	Table 11.2 (**)
Slope	Dim. less	1.51	1.51	1.51	1.51	1.51	Table 11.2 (**)
Intercept	Dim. less	0.520	0.520	0.520	0.520	0.520	Table 11.2 (**)
AG_{DM}	kg dm ha^{-1} yr^{-1}	10,054	9,656	8,042	10,027	7,437	Table 11.2 (**)
N_{AG}	kg N kg dm^{-1}	0.0060	0.006	0.006	0.006	0.0060	Table 11.2 (**)
$Frac_{Remove}$	kg N kg crop-N^{-1}	0.134	0.329	0.333			See text
$R_{BG\text{-}BIO}$	kg dm kg dm^{-1}	0.240	0.240	0.240	0.240	0.240	Table 11.2 (**)
N_{BG}	kg N kg dm^{-1}	0.0090	0.009	0.009	0.009	0.0090	Table 11.2 (**)
F_{SOM}	kg N yr^{-1}						See text
F_{OS}	ha	0.05	0.02	0.02	0.03	0.02	See text
F_{PRP}	kg N yr^{-1}						No grazing
EF_1	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	Table 11.1 (**)
EF_2	kg N_2O–N ha^{-1} yr^{-1}	8.00	8.00	8.00	8.00	8.00	Table 11.1 (**)
EF_{3PRP}	kg N_2O–N kg N^{-1}	0.02	0.02	0.02	0.02	0.02	Table 11.1 (**)
$Frac_{GASF}$	kg N kg N^{-1}	0.1	0.1	0.1	0.1	0.1	Table 11.3 (**)
$Frac_{GASM}$	kg N kg N^{-1}	0.2	0.2	0.2	0.2	0.2	Table 11.3 (**)
$Frac_{EACH}$	kg N kg N^{-1}	0.3	0.3	0.3	0.3	0.3	Table 11.3 (**)
EF_4	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	Table 11.3 (**)
EF_5	kg N_2O–N kg N^{-1}	0.00750	0.0075	0.0075	0.0075	0.0075	Table 11.3 (**)

The N inputs, outputs and emissions related to wheat cultivation are presented in Table 5.40. $N_{surplus}$ equals the sum of the N emissions, and the N balance is calculated as N surplus minus N emissions. When the N balance equals 0, it means all N is accounted for.

Table 5.40: N balances and emissions related to wheat cultivation. (*): Schmidt and Dalgaard (2012). Unit: kg N ha^{-1} yr^{-1}.

Parameter	Wheat					Source
	DE	DK	SE	UK	EU27	
N inputs						
N-fert: Ammonia		2.58			0.082	Table 5.2
N-fert: Urea	31.5	0.4		32.0	17.5	Table 5.2
N-fert: AN		3.44	5.13	80.4	16.1	Table 5.2
N-fert: CAN	55.8	35.2	67.4	13.0	19.0	Table 5.2
N-fert: AS	7.07	2.58		6.92	2.34	Table 5.2
Manure	118	111	88.7	121	83.4	Table 5.2
Crop residues left in field	74.0	59.7	49.6	81.8	60.7	Table 5.2
Total N_{input}	**286**	**215**	**211**	**335**	**199**	Equation 7.1(*)
N outputs						
Harvested crop	116	111	91.7	116	84.3	Table 5.2
Crop residues removed	15.5	36.6	30.5			Table 5.2
Total N_{output}	**132**	**66.6**	**122**	**116**	**84,3**	Equation 7.1(*)
N inputs - N outputs						
$N_{surplus}$	155	60.9	88.6	219	115	Equation 7.1(*)
N emissions						
NH_3-N	28.1	22.6	21.2	31.8	18.8	Section 7.4 (*)
NO_x-N	4.96	3.98	3.75	5.61	3.33	Section 7.4 (*)
N_2O-N_{direct}	3.24	2.30	2.26	3.57	2.12	Equation 7.3(*)
N_2-N	32.5	-26.6	-1.87	77.7	30.7	Section 7.4 (*)
NO_3-N	85.9	64.4	63.2	101	59.7	Section 7.4 (*)
N balance	0	0	0	0	0	See text

Oat, corn and soybean

The parameters used for calculation of emissions from cultivation of oat, corn and soybean are presented in Table 5.41.

Table 5.41: Parameters used for calculation of emissions from cultivation of oat, corn and soybeans. (*): Schmidt and Dalgaard (2012). (**): IPCC (2006).

Parameter	Crop: Country: Unit:	Oat				Corn	Soybean	Source
		DE	DK	SE	UK	EU27	BR	
$N_2O\text{-}N_{direct}$	kg N_2O–N ha^{-1} yr^{-1}	1.83	1.17	1.17	1.75	1.78	0.543	Equation 7.3(*)
$N_2O\text{-}N_{indirect}$	kg N_2O–N ha^{-1} yr^{-1}	0.642	0.412	0.404	0.585	0.603	0.145	Equation 7.5(*)
$N_2O\text{-}N_{N\ input}$	kg N_2O–N ha^{-1} yr^{-1}	1.83	1.17	1.17	1.75	1.78	0.543	Equation 7.3(*)
$N_2O\text{-}N_{OS}$	kg N_2O–N ha^{-1} yr^{-1}	0.376	0.15	0.152	0.224	0.128	0.032	Equation 7.3(*)
$N_2O\text{-}N_{PRP}$	kg N_2O–N ha^{-1} yr^{-1}							Equation 7.3(*)
F_{SN}	kg N ha^{-1} yr^{-1}	65.8	24.7	41.0	67.6	49.9	13.4	Table 5.3
F_{ON}	kg N ha^{-1} yr^{-1}	82.3	61.6	50.1	61.8	75.8	4.79	Table 5.3
F_{CR}	kg N ha^{-1} yr^{-1}	34.7	31.0	25.9	45.5	52.5	36.1	Equation 7.3(*)
Crop	kg DM ha^{-1} yr^{-1}	3,933	4,000	3,235	4,575	6,169	2,625	Table 11.2 (**)
Slope	Dim. less	0.910	0.910	0.910	0.910	1.03	0.930	Table 11.2 (**)
Intercept	Dim. less	0.890	0.890	0.890	0.890	0.610	1.35	Table 11.2 (**)
AG_{DM}	kg dm ha^{-1} yr^{-1}	4,469	4,530	3,834	5,053	6,964	3,791	Table 11.2 (**)
N_{AG}	kg N kg dm^{-1}	0.0070	0.007	0.007	0.007	0.0060	0.0080	Table 11.2 (**)
$Frac_{Remove}$	kg N kg crop-N^{-1}	0.176	0.307	0.321				See text
$R_{BG\text{-}BIO}$	kg dm kg dm^{-1}	0.250	0.250	0.250	0.250	0.220	0.190	Table 11.2 (**)
N_{BG}	kg N kg dm^{-1}	0.0080	0.008	0.008	0.008	0.0070	0.0080	Table 11.2 (**)
F_{SOM}	kg N yr^{-1}							See text
F_{OS}	ha	0.05	0.02	0.02	0.03	0.02	0.00	See text
F_{PRP}	kg N yr^{-1}							No grazing
EF_1	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	Table 11.1 (**)
EF_2	kg N_2O–N ha^{-1} yr^{-1}	8.00	8.00	8.00	8.00	8.00	16.0	Table 11.1 (**)
EF_{3PRP}	kg N_2O–N kg N^{-1}	0.02	0.02	0.02	0.02	0.02	0.02	Table 11.1 (**)
$Frac_{GASF}$	kg N kg N^{-1}	0.1	0.1	0.1	0.1	0.1	0.1	Table 11.3 (**)
$Frac_{GASM}$	kg N kg N^{-1}	0.2	0.2	0.2	0.2	0.2	0.2	Table 11.3 (**)
$Frac_{EACH}$	kg N kg N^{-1}	0.3	0.3	0.3	0.3	0.3	0.3	Table 11.3 (**)
EF_4	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	Table 11.3 (**)
EF_5	kg N_2O–N kg N^{-1}	0.00750	0.0075	0.0075	0.0075	0.0075	0.0075	Table 11.3 (**)

The N inputs, outputs and emissions related to oat, corn and soybean cultivation are presented in Table 5.42. $N_{surplus}$ equals the sum of the N emissions, and the N balance is calculated as N surplus minus N emissions. When the N balance equals 0, it means all N is accounted for.

Table 5.42: N balances and emissions related to oat, corn and soybean cultivation. (*): Schmidt and Dalgaard (2012). Unit: kg N ha^{-1} yr^{-1}.

Parameter	Oat				Corn	Soybean	Source
	DE	DK	SE	UK	EU27	BR	
N inputs							
N-fert: Ammonia		1.44			0.074		Table 5.3
N-fert: Urea	22.0	0.239		16.3	15.9	8.56	Table 5.3
N-fert: AN		1.91	2.90	41.1	14.6	2.38	Table 5.3
N-fert: CAN	38.9	19.6	38.1	6.62	17.2	0.416	Table 5.3
N-fert: AS	4.93	1.44		3.53	2.13	2.01	Table 5.3
Manure	82.3	61.6	50.1	61.8	75.8	4.79	Table 5.3
Crop residues left in field	34.7	31.0	25.9	45.5	52.5	36.1	Table 5.3
Total N_{input}	**183**	**117**	**117**	**175**	**178**		Equation 7.1(*)
N outputs							
Harvested crop	64.2	65.3	52.8	74.7	94.8	173	Table 5.3
Crop residues removed	11.3	20.1	17.0				Table 5.3
Total N_{output}	**75.5**	**85.3**	**69.8**	**74.7**	**94.8**	**173**	Equation 7.1(*)
N inputs - N outputs							
$N_{surplus}$	107	32	100	97.2	83.5	-118	Equation 7.1(*)
N emissions							
NH_3-N	19.6	12.6	12.0	16.2	17.1	1.95	Section 7.4 (*)
NO_x-N	3.46	2.22	2.12	2.87	3.02	0.344	Section 7.4 (*)
N_2O-N_{direct}	2.20	1.32	1.32	1.97	1.91	0.575	Equation 7.3(*)
N_2-N	27.3	-19.3	-3.34	26.6	7.95	-137	Section 7.4 (*)
NO_3-N	54.8	35.2	35.1	52.4	53.5	16.3	Section 7.4 (*)
N balance	19.6	0	0	0	0	0	See text

Rapeseed, sunflower, sugar beet and oil palm

The parameters used for calculation of emissions from cultivation of rapeseed, sunflower, sugar beet and oil palm are presented in Table 5.43.

Table 5.43: Parameters used for calculation of emissions from cultivation of rapeseed, sunflower, sugar beet and oil palm. (*): Schmidt and Dalgaard (2012). (**): IPCC (2006).

Parameter	Crop:	Rapeseed	Sunflower	Sugar beet				Oil palm	Source
	Country: Unit:	EU27	FR	DE	DK	SE	UK	MY/ID	
N_2O-N_{direct}	kg N_2O–N ha^{-1} yr^{-1}	1.74	0.764	5.81	4.63	4.62	5.03	3.62	Equation 7.3(*)
N_2O-$N_{indirect}$	kg N_2O–N ha^{-1} yr^{-1}	0.620	0.251	1.60	1.23	1.24	1.33	0.977	Equation 7.5(*)
N_2O-$N_{N\ input}$	kg N_2O–N ha^{-1} yr^{-1}	1.74	0.764	5.81	4.63	4.62	5.03	3.62	Equation 7.3(*)
N_2O-N_{OS}	kg N_2O–N ha^{-1} yr^{-1}	0.128	0.128	0.376	0.15	0.152	0.224	2.88	Equation 7.3(*)
N_2O-N_{PRP}	kg N_2O–N ha^{-1} yr^{-1}							0	Equation 7.3(*)
F_{SN}	kg N ha^{-1} yr^{-1}	56.6	20.1	82.9	30	58.4	68.3	162	Table 5.4
F_{ON}	kg N ha^{-1} yr^{-1}	85.9	29.6	104	76.1	71.4	62.4	0.580	Table 5.4
F_{CR}	kg N ha^{-1} yr^{-1}	31.4	26.7	394	357	332	372	199	Equation 7.3(*)
Crop	kg DM ha^{-1} yr^{-1}	2,801	2,263	15,603	14,048	13,001	14,699	8,112	Table 11.2 (**)
Slope	Dim. less	1.09	1.09	1.09	1.09	1.09	1.09	0	Table 11.2 (**)
Intercept	Dim. less	0.880	0.880	1.06	1.06	1.06	1.06	0	Table 11.2 (**)
AG_{DM}	kg dm ha^{-1} yr^{-1}	3,933	3,346	18,067	16,372	15,231	17,082	15,113	Table 11.2 (**)
N_{AG}	kg N kg dm^{-1}	0.006	0.006	0.019	0.019	0.0190	0.019	0	Table 11.2 (**)
$Frac_{Remove}$	kg N kg crop-N^{-1}							0	See text
R_{BG-BIO}	kg dm kg dm^{-1}	0.220	0.220	0.200	0.200	0.200	0.200	0	Table 11.2 (**)
N_{BG}	kg N kg dm^{-1}	0.00900	0.00900	0.0140	0.014	0.014	0.014	0	Table 11.2 (**)
F_{SOM}	kg N yr^{-1}							0	See text
F_{OS}	ha	0.02	0.02	0.05	0.02	0.02	0.03	0.1800	See text
F_{PRP}	kg N yr^{-1}							0	No grazing
EF_1	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	0.0100	Table 11.1 (**)
EF_2	kg N_2O–N ha^{-1} yr^{-1}	8.00	8.00	8.00	8.00	8.00	8.00	16.0	Table 11.1 (**)
EF_{3PRP}	kg N_2O–N kg N^{-1}	0.02	0.02	0.02	0.02	0.02	0.02	0.0200	Table 11.1 (**)
$Frac_{GASF}$	kg N kg N^{-1}	0.1	0.1	0.1	0.1	0.1	0.1	0.100	Table 11.3 (**)
$Frac_{GASM}$	kg N kg N^{-1}	0.2	0.2	0.2	0.2	0.2	0.2	0.200	Table 11.3 (**)
$Frac_{LEACH}$	kg N kg N^{-1}	0.3	0.3	0.3	0.3	0.3	0.3	0.300	Table 11.3 (**)
EF_4	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	0.0100	Table 11.3 (**)
EF_5	kg N_2O–N kg N^{-1}	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	Table 11.3 (**)

The N inputs, outputs and emissions related to rapeseed, sunflower, sugar beet and oil palm cultivation are presented in Table 5.44. $N_{surplus}$ equals the sum of the N emissions, and the N balance is calculated as N surplus minus N emissions. When the N balance equals 0, it means all N is accounted for.

Table 5.44: N balances and emissions related to rapeseed, sunflower, sugar beet and oil palm cultivation. (*): Schmidt and Dalgaard (2012). Unit: kg N ha^{-1} yr^{-1}.

Parameter	Rapeseed	Sunflower	Sugar beet				Oil palm	Source
	EU27	FR	DE	DK	SE	UK	MY/ID	
N inputs								
N-fert: Ammonia	0.084			1.77			0	Table 5.4
N-fert: Urea	18.0	5.33	27.7	0.296		16.5	151	Table 5.4
N-fert: AN	16.5	10.0		2.37	4.13	41.51	10.8	Table 5.4
N-fert: CAN	19.5	4.43	49.0	24.2	54.3	6.69	0	Table 5.4
N-fert: AS	2.42	0.269	6.22	1.77		3.57	0	Table 5.4
Manure	85.9	29.6	104	76.1	71.4	62.4	0.580	Table 5.4
Crop residues left in field	31.4	26.7	394	357	332	372	199	Table 5.4
Total N_{input}	**174**	**76.4**	**581**	**463**	**462**	**503**	**362**	Equation 7.1(*)
N outputs								
Harvested crop	86.9	66.6	147	133	123	139	44.6	Table 5.4
Crop residues removed							0	Table 5.4
Total N_{output}	**86.9**	**66.6**	**147**	**133**	**123**	**139**	**362**	Equation 7.1(*)
N inputs - N outputs								
$N_{surplus}$	87.0	9.80	433	339	312	364	317	Equation 7.1(*)
N emissions								
NH_3-N	19.4	6.74	24.7	15.5	17.1	16.4	13.9	Section 7.4 (*)
NO_x-N	3.43	1.19	4.36	2.74	3.02	2.90	2.44	Section 7.4 (*)
N_2O-N_{direct}	1.87	0.892	6.18	4.79	4.77	5.26	6.50	Equation 7.3(*)
N_2-N	10.1	-22.0	224	169	176	189	186	Section 7.4 (*)
NO_3-N	52.2	22.9	174	139	139	151	108	Section 7.4 (*)
N balance	0	0	0	0	0	0	0	See text

Permanent grass incl. grass ensilage

The parameters used for calculation of emissions from cultivation of permanent grass incl. grass ensilage are presented in Table 5.45.

Table 5.45: Parameters used for calculation of emissions from cultivation of permanent grass incl. grass ensilage. (*): Schmidt and Dalgaard (2012). (**): IPCC (2006).

Parameter	Crop: Country: Unit:	Permanent grass incl. grass ensilage					Source
		DE	DK	SE	UK	BR	
N_2O-N_{direct}	kg N_2O–N ha^{-1} yr^{-1}	1.59	0.960	1.76	1.26	1.29	Equation 7.3(*)
N_2O-$N_{indirect}$	kg N_2O–N ha^{-1} yr^{-1}	0.465	0.264	0.496	0.311	0.276	Equation 7.5(*)
N_2O-$N_{N\ input}$	kg N_2O–N ha^{-1} yr^{-1}	1.19	0.668	1.18	0.500	0.137	Equation 7.3(*)
N_2O-N_{OS}	kg N_2O–N ha^{-1} yr^{-1}	0.808	0.360	0.360	0.648	0.02	Equation 7.3(*)
N_2O-N_{PRP}	kg N_2O–N ha^{-1} yr^{-1}	0.401	0.292	0.581	0.756	1.15	Equation 7.3(*)
F_{SN}	kg N ha^{-1} yr^{-1}	111	51.4	106	37.9	1.00	Table 5.5
F_{ON}	kg N ha^{-1} yr^{-1}						Table 5.5
F_{CR}	kg N ha^{-1} yr^{-1}	7.97	15.4	12.4	12.1	12.7	Equation 7.3(*)
Crop	kg DM ha^{-1} yr^{-1}	1,080	2,093	1,674	1,645	1,725	Table 11.2 (**)
Slope	Dim. less	0.300	0.300	0.300	0.300	0.300	Table 11.2 (**)
Intercept	Dim. less						Table 11.2 (**)
AG_{DM}	kg dm ha^{-1} yr^{-1}	324	628	502	493	518	Table 11.2 (**)
N_{AG}	kg N kg dm^{-1}	0.015	0.015	0.015	0.015	0.015	Table 11.2 (**)
$Frac_{Remove}$	kg N kg crop-N^{-1}						See text
$R_{BG\text{-}BIO}$	kg dm kg dm^{-1}	0.800	0.800	0.800	0.800	0.800	Table 11.2 (**)
N_{BG}	kg N kg dm^{-1}	0.0120	0.0120	0.012	0.012	0.0120	Table 11.2 (**)
F_{SOM}	kg N yr^{-1}						See text
F_{OS}	ha	0.10	0.05	0.05	0.08	0.00	See text
F_{PRP}	kg N yr^{-1}	20.0	14.6	29.1	37.8	57.4	No grazing
EF_1	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	Table 11.1 (**)
EF_2	kg N_2O–N ha^{-1} yr^{-1}	8.00	8.00	8.00	8.00	8.00	Table 11.1 (**)
EF_{3PRP}	kg N_2O–N kg N^{-1}	0.02	0.02	0.02	0.02	0.02	Table 11.1 (**)
$Frac_{GASF}$	kg N kg N^{-1}	0.1	0.1	0.1	0.1	0.1	Table 11.3 (**)
$Frac_{GASM}$	kg N kg N^{-1}	0.2	0.2	0.2	0.2	0.2	Table 11.3 (**)
$Frac_{EACH}$	kg N kg N^{-1}	0.3	0.3	0.3	0.3	0.3	Table 11.3 (**)
EF_4	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	Table 11.3 (**)
EF_5	kg N_2O–N kg N^{-1}	0.0075	0.0075	0.0075	0.0075	0.0075	Table 11.3 (**)

The N inputs, outputs and emissions related to cultivation of permanent grass incl. grass ensilage are presented in Table 5.46. $N_{surplus}$ equals the sum of the N emissions, and the N balance is calculated as N surplus minus N emissions.

Table 5.46: N balances and emissions related to cultivation of permanent grass incl. grass ensilage. (*): Schmidt and Dalgaard (2012). Unit: kg N ha^{-1} yr^{-1}.

Parameter	Permanent grass incl. grass ensilage					Source
	DE	DK	SE	UK	BR	
N inputs						
N-fert: Ammonia	37.2	2.99				Table 5.5
N-fert: Urea		0.499		9.2	0.640	Table 5.5
N-fert: AN	65.8	3.99	7.50	23.0	0.178	Table 5.5
N-fert: CAN	8.34	40.9	98.5	3.71	0.031	Table 5.5
N-fert: AS	20.0	2.99		1.98	0.151	Table 5.5
Manure	7.97	14.6	29.1	37.8	57.4	Table 5.5
Crop residues left in field	37.2	15.4	12.4	12.1	12.7	Table 5.5
Total N_{input}	**139**	**81.4**	**147**	**87.8**	**71.2**	Equation 7.1(*)
N outputs						
Harvested crop	34.6	67.0	53.6	52.6	55.2	Table 5.5
Crop residues removed						Table 5.5
Total N_{output}	**34.6**	**67.0**	**53.6**	**52.6**	**55.2**	Equation 7.1(*)
N inputs - N outputs						
$N_{surplus}$	105	14.4	93.8	35.2	16	Equation 7.1(*)
N emissions						
NH_3-N	12.9	6.85	13.9	9.65	9.85	Section 7.4 (*)
NO_x-N	2.27	1.21	2.46	1.70	1.74	Section 7.4 (*)
N_2O-N_{direct}	2.40	1.32	2.12	1.90	1.30	Equation 7.3(*)
N_2-N	45.4	-19.4	31.1	-4.40	-18.3	Section 7.4 (*)
NO_3-N	41.8	24.4	44.2	26.3	21.4	Section 7.4 (*)
N balance	0	0	0	0	0	See text

Rotation grass, incl. grass ensilage and roughage, maize ensilage

The parameters used for calculation of emissions from cultivation of rotation grass, incl. grass ensilage and roughage, maize ensilage are presented in Table 5.47.

Table 5.47: Parameters used for calculation of emissions from cultivation of rotation grass, incl. grass ensilage and roughage, maize ensilage. (*): Schmidt and Dalgaard (2012). (**): IPCC (2006).

Parameter	Crop:	Rotation grass, incl. grass ensilage				Roughage, maize ensilage				Source
	Country: Unit:	DE	DK	SE	UK	DE	DK	SE	UK	
$N_2O\text{-}N_{direct}$	kg N_2O–N ha^{-1} yr^{-1}	3.22	3.99	2.47	2.89	2.33	3.21	1.85	1.80	Equation 7.3(*)
$N_2O\text{-}N_{indirect}$	kg N_2O–N ha^{-1} yr^{-1}	0.880	1.06	0.633	0.698	0.558	0.74	0.435	0.437	Equation 7.5(*)
$N_2O\text{-}N_{N\ input}$	kg N_2O–N ha^{-1} yr^{-1}	2.63	2.98	2.00	1.59	1.11	1.17	1.16	1.02	Equation 7.3(*)
$N_2O\text{-}N_{OS}$	kg N_2O–N ha^{-1} yr^{-1}	0.376	0.152	0.152	0.224	0.38	0.15	0.152	0.224	Equation 7.3(*)
$N_2O\text{-}N_{PRP}$	kg N_2O–N ha^{-1} yr^{-1}	0.589	1.01	0.461	1.30	1.22	2.04	0.691	0.77	Equation 7.3(*)
F_{SN}	kg N ha^{-1} yr^{-1}	164	178	84.1	64.9	49	40.8	28.3	42.3	Table 5.6, Table
F_{ON}	kg N ha^{-1} yr^{-1}									Table 5.6, Table
F_{CR}	kg N ha^{-1} yr^{-1}	98.9	120	116	94.3	62.7	76	87.3	59.8	Equation 7.3(*)
Crop	kg DM ha^{-1} yr^{-1}	7,393	8,973	8,698	7,050	9,737	11,818	9,677	9,286	Table 11.2 (**)
Slope	Dim. less	0.300	0.300	0.300	0.300	0.300	0.300	0.910	0.300	Table 11.2 (**)
Intercept	Dim. less							0.890		Table 11.2 (**)
AG_{DM}	kg dm ha^{-1} yr^{-1}	2,218	2,692	2,610	2,115	2,921	3,545	9,696	2,786	Table 11.2 (**)
N_{AG}	kg N kg dm^{-1}	0.027	0.027	0.027	0.027	0.015	0.015	0.007	0.015	Table 11.2 (**)
$Frac_{Remove}$	kg N kg crop-N^{-1}									See text
$R_{BG\text{-}BIO}$	kg dm kg dm^{-1}	0.800	0.800	0.800	0.800	0.540	0.540	0.250	0.540	Table 11.2 (**)
N_{BG}	kg N kg dm^{-1}	0.0220	0.0220	0.022	0.022	0.0120	0.0120	0.008	0.012	Table 11.2 (**)
F_{SOM}	kg N yr^{-1}									See text
F_{OS}	ha	0.05	0.02	0.02	0.03	0.05	0.02	0.02	0.03	See text
F_{PRP}	kg N yr^{-1}	29.5	50.5	23.0	64.8	60.8	102	34.5	38.7	Section 0
EF_1	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Table 11.1 (**)
EF_2	kg N_2O–N ha^{-1} yr^{-1}	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	Table 11.1 (**)
EF_{3PRP}	kg N_2O–N kg N^{-1}	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	Table 11.1 (**)
$Frac_{GASF}$	kg N kg N^{-1}	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	Table 11.3 (**)
$Frac_{GASM}$	kg N kg N^{-1}	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	Table 11.3 (**)
$Frac_{EACH}$	kg N kg N^{-1}	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	Table 11.3 (**)
EF_4	kg N_2O–N kg N^{-1}	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Table 11.3 (**)
EF_5	kg N_2O–N kg N^{-1}	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	Table 11.3 (**)

The N inputs, outputs and emissions related to cultivation of rotation grass, incl. grass ensilage and roughage, maize ensilage are presented in Table 5.48. $N_{surplus}$ equals the sum of the N emissions, and the N balance is calculated as $N_{surplus}$ minus N emissions. When the N balance equals 0, it means all N is accounted for.

Table 5.48: N balances and emissions related to cultivation of rotation grass, incl. grass ensilage and roughage, maize ensilage. (*): Schmidt and Dalgaard (2012). Unit: kg N ha^{-1} yr^{-1}.

Parameter	Rotation grass, incl. grass ensilage				Roughage, maize ensilage				Source
	DE	DK	SE	UK	DE	DK	SE	UK	
N inputs									
N-fert: Ammonia		10.4				2.38			Table 5.6, Table 5.7
N-fert: Urea	54.7	1.73		15.7	16.2	0.396		10.2	Table 5.6, Table 5.7
N-fert: AN		13.8	5.94	39.4		3.17	2.00	25.7	Table 5.6, Table 5.7
N-fert: CAN	96.7	142	78.1	6.36	28.7	32.5	26.3	4.15	Table 5.6, Table 5.7
N-fert: AS	12.3	10.4		3.39	3.64	2.38		2.21	Table 5.6, Table 5.7
Manure	29.5	50.5	23.0	64.8	60.8	102	34.5	38.7	Table 5.6, Table 5.7
Crop residues left in field	98.9	120	116	94.3	62.7	76.2	87.3	59.8	Table 5.6, Table 5.7
Total N_{input}	**292**	**349**	**223**	**224**	**172**	**219**	**150**	**141**	Equation 7.1(*)
N outputs									
Harvested crop	189	230	223	180	123	149	163	117	Table 5.6, Table 5.7
Crop residues removed									Table 5.6, Table 5.7
Total N_{output}	**189**	**230**	**223**	**180**	**123**	**149**	**163**	**117**	Equation 7.1(*)
N inputs - N outputs									
$N_{surplus}$	103	119	0.790	43.5	49.1	69.6	-12.5	23.5	Equation 7.1(*)
N emissions									
NH_3-N	18.9	23.7	11.1	16.5	14.5	20.8	8.28	10.2	Section 7.4 (*)
NO_x-N	3.34	4.18	1.95	2.92	2.55	3.67	1.46	1.80	Section 7.4 (*)
N_2O-N_{direct}	3.59	4.14	2.62	3.11	2.71	3.36	2.00	2.02	Equation 7.3(*)
N_2-N	-10.7	-17.8	-81.9	-46.2	-22.3	-24.0	-69.3	-32.8	Section 7.4 (*)
NO_3-N	87.6	105	67.0	67.2	51.7	65.7	45.0	42.3	Section 7.4 (*)
N balance	0	0	11.1	0	0	0	0	0	See text

5.3 Summary of the LCI of plant cultivation

Barley

LCI of barley cultivation system is presented in Table 5.49.

Table 5.49: LCI of barley cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Barley					
		DE	DK	SE	UK	UA	EU27
Output of products							
Determining product: Barley	kg	6,136	5,382	4,422	5,641	2,358	4,430
Material for treatment: Straw	kg		1,889	1,591			
Input of products							
N-fert: Ammonia	kg N		1.81			3.10	0.07
N-fert: Urea	kg N	28.7	0.30		20.1	4.25	15.9
N-fert: AN	kg N		2.41	3.40	50.6	12.5	14.6
N-fert: CAN	kg N	50.7	24.7	44.7	8.17	0.85	17.2
N-fert: AS	kg N	6.43	1.81		4.36	0.14	2.13
Manure	kg N	107	77.6	58.7	76.2	11.3	75.8
P fert: TSP	kg P_2O_5	6.31	3.88	0.78	10.2	2.32	5.18
K fert: KCl	kg K_2O	10.1	9.14	1.25	28.8	2.09	5.45
Pesticides	kg a.i.	0.509	0.51	0.509	0.51	0.509	0.509
Lorry	tkm	66.8	29.9	36.7	71.2	14.3	38.1
Diesel	MJ	3,046	3,046	3,046	3,046	3,046	3,046
Light fuel oil for drying	MJ	1.10	1.10	1.10	1.10	1.10	1.10
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00	1.00	1.00
Services (per ha year)	p	1.00	1.00	1.00	1.00	1.00	1.00
Land tenure, arable	kg C	6,500	7,000	5,600	5,500	5,000	7,000
Emissions							
NH_3-N	kg N_2O	3.83	2.35	2.22	3.34	0.910	2.65
NO_x-N	kg N_2O	1.33	0.82	0.759	1.12	0.273	0.91
N_2O-N_{direct}	kg NH_3	31.0	19.2	17.1	24.3	4.49	20.8
N_2-N	kg NO_x	9.66	5.99	5.32	7.57	1.40	6.48
NO_3-N	kg NO_3	3.83	199	188	283	76.9	224

Wheat

LCI of wheat cultivation systems is presented in Table 5.50.

Table 5.50: LCI of wheat cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Wheat				
		DE	DK	SE	UK	EU27
Output of products						
Determining product: Wheat	kg	7,428	7,118	5,860	7,407	5,389
Material for treatment: Straw	kg		3,594	2,993		
Input of products						
N-fert: Ammonia	kg N		2.58			0.082
N-fert: Urea	kg N	31.5	0.43		32.0	17.5
N-fert: AN	kg N		3.44	5.13	80.4	16.1
N-fert: CAN	kg N	55.8	35.2	67.4	13.0	19.0
N-fert: AS	kg N	7.07	2.58		6.92	2.34
Manure	kg N	118	111	88.7	121	83.4
P fert: TSP	kg P_2O_5	6.31	3.88	0.91	7.85	5.18
K fert: KCl	kg K_2O	16.9	15.3	1.14	20.0	9.13
Pesticides	kg a.i.	0.603	0.603	0.603	0.603	0.603
Lorry	tkm	75.2	41.8	54.7	94.3	42.7
Diesel	MJ	3,306	3,306	3,306	3,306	3,306
Light fuel oil for drying	MJ	1.10	1.10	1.10	1.10	1.10
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00	1.00
Services (per ha year)	p	1.00	1.00	1.00	1.00	1.00
Land tenure, arable	kg C	6,500	7,000	5,600	5,500	7,000
Emissions						
Dinitrogen monoxide (direct)	kg N_2O	4.50	3.37	3.31	5.26	3.13
Dinitrogen monoxide (indirect)	kg N_2O	1.53	1.18	1.14	1.77	1.05
Ammonia	kg NH_3	34.1	27.4	25.8	38.6	22.9
Nitrogen oxides	kg NO_x	10.6	8.5	8.03	12.0	7.13
Nitrate	kg NO_3	381	285	280	445	264

Oat, corn and soybean

LCI of oat, corn and soybean cultivation systems is presented in Table 5.51.

Table 5.51: LCI of oat, corn and soybean cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Oat DE	Oat DK	Oat SE	Oat UK	Corn EU27	Soybean BR
Output of products							
Determining product: Oat/corn/soybean	kg	4,627	4,706	3,806	5,382	7,051	2,903
Material for treatment: Straw	kg		1,686	1,427			
Input of products							
N-fert: Ammonia	kg N		1.44			0.074	
N-fert: Urea	kg N	22.0	0.24		16.3	15.9	8.56
N-fert: AN	kg N		1.91	2.90	41.1	14.6	2.38
N-fert: CAN	kg N	38.9	19.6	38.1	6.62	17.2	0.416
N-fert: AS	kg N	4.93	1.44		3.53	2.13	2.01
Manure	kg N	82.3	61.6	50.1	61.8	75.8	4.79
P fert: TSP	kg P_2O_5	7.17	4.40	0.78	8.79	8.95	29.7
K fert: KCl	kg K_2O	12.0	10.8	1.14	22.5	7.36	51.3
Pesticides	kg a.i.	0.355	0.35	0.35	0.35	3.53	2.50
Lorry	tkm	55.2	26.5	31.4	57.9	44.4	59.0
Diesel	MJ	3,046	3,046	3,046	3,046	3,306	1,709
Light fuel oil for drying	MJ	1.10	1.10	1.10	1.10	1.10	1.10
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00	1.00	1.00
Services (per ha year)	p	1.00	1.00	1.00	1.00	1.00	1.00
Land tenure, arable	kg C	6,500	7,000	5,600	5,500	7,000	9,000
Emissions							
Dinitrogen monoxide (direct)	kg N_2O	2.87	1.84	1.84	2.75	2.80	0.853
Dinitrogen monoxide (indirect)	kg N_2O	1.01	0.65	0.635	0.919	0.947	0.228
Ammonia	kg NH_3	23.8	15.3	14.6	19.7	20.8	2.37
Nitrogen oxides	kg NO_x	7.41	4.75	4.54	6.14	6.48	0.738
Nitrate	kg NO_3	243	156	155	232	237	72.1

Rapeseed, sunflower, sugar beet and oil palm cultivation

LCI of rapeseed, sunflower, sugar beet and oil palm cultivation systems is presented in Table 5.52.

Table 5.52: LCI of rapeseed, sunflower, sugar beet and oil palm cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Rapeseed	Sunflower	Sugar beet				Oil palm
		EU27	FR	DE	DK	SE	UK	MY/ID
Output of products								
Determining product: Rapeseed/sunflower/sugar beet/oil palm	kg	3,028	2,459	70,922	63,855	59,094	66,812	17,260
Material for treatment: Straw	kg							
Input of products								
N-fert: Ammonia	kg N	0.084			1.77			
N-fert: Urea	kg N	18.0	5.33	27.7	0.30		16.5	151
N-fert: AN	kg N	16.5	10.0		2.37	4.13	41.5	10.8
N-fert: CAN	kg N	19.5	4.43	49.0	24.2	54.3	6.69	
N-fert: AS	kg N	2.42	0.269	6.22	1.77		3.57	
Manure	kg N	85.9	29.6	104	76.1	71.4	62.4	0.580
P fert: TSP	kg P_2O_5	7.54	3.68	12.6	7.75	2.08	7.22	35.5
K fert: KCl	kg K_2O	11.5	6.87	35.3	31.9	4.05	45.1	222
Pesticides	kg a.i.	0.270	0.270	2.74	2.74	2.74	2.74	2.60
Lorry	tkm	46.8	18.4	82.7	43.8	48.0	67.3	198
Diesel	MJ	3,195	3,306	8,581	8,581	8,581	8,581	1,710
Light fuel oil for drying	MJ	1.10	1.10					
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Services (per ha year)	p	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Land tenure, arable	kg C	7,000	7,000	6,500	7,000	5,600	7,000	11,000
Emissions								
Dinitrogen monoxide (direct)	kg N_2O	2.73	1.20	9.12	7.28	7.26	7.91	5.68
Dinitrogen monoxide (indirect)	kg N_2O	0.974	0.395	2.51	1.93	1.95	2.08	1.53
Ammonia	kg NH_3	23.6	8.19	30.0	18.9	20.8	19.9	16.8
Nitrogen oxides	kg NO_x	7.34	2.55	9.34	5.87	6.47	6.21	5.24
Nitrate	kg NO_3	231	102	771	616	614	668	5.68

Permanent grass

LCI of permanent grass cultivation systems is presented in Table 5.53.

Table 5.53: LCI of permanent grass cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Permanent grass				
		DE	DK	SE	UK	BR
Output of products						
Determining product: Permanent grass	kg	6,000	11,628	9,302	9,136	9,585
Material for treatment: Straw	kg					
Input of products						
N-fert: Ammonia	kg N		2.99			
N-fert: Urea	kg N	37.2	0.50		9.16	0.640
N-fert: AN	kg N		3.99	7.50	23.0	0.178
N-fert: CAN	kg N	65.8	40.9	98.5	3.71	0.0311
N-fert: AS	kg N	8.34	2.99		1.98	0.151
Manure	kg N	20.0	14.6	29.1	37.8	57.4
P fert: TSP	kg P_2O_5	3.73	1.41	1.69	2.51	
K fert: KCl	kg K_2O	18.8	10.2	8.31	6.44	
Pesticides	kg a.i.	0.095	0.095	0.0950	0.095	
Lorry	tkm	84.1	42.0	82.5	27.4	0.551
Diesel	MJ	557	557	557	557	32.3
Light fuel oil for drying	MJ					
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00	
Services (per ha year)	p	1.00	1.00	1.00	1.00	
Land tenure, arable	kg C	6,500	7,000	2,800	5,500	
Land tenure, intensive forest land	kg C			2,800		
Land tenure, rangeland	kg C					9,000
Emissions						
Dinitrogen monoxide (direct)	kg N_2O	2.50	1.51	2.77	1.97	2.02
Dinitrogen monoxide (indirect)	kg N_2O	0.730	0.414	0.779	0.489	0.434
Ammonia	kg NH_3	15.6	8.32	16.9	11.7	12.0
Nitrogen oxides	kg NO_x	4.87	2.59	5.28	3.65	3.72
Nitrate	kg NO_3	185	108	196	117	94.6

Rotation grass, incl. grass ensilage

LCI of rotation grass, incl. grass ensilage cultivation systems is presented in Table 5.54.

Table 5.54: LCI of rotation grass, incl. grass ensilage cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Rotation grass, incl. grass ensilage			
		DE	DK	SE	UK
Output of products					
Determining product: Rotation grass	kg	19,455	23,613	22,890	18,533
Input of products					
N-fert: Ammonia	kg N		10.4		
N-fert: Urea	kg N	54.7	1.73		15.7
N-fert: AN	kg N		13.8	5.94	39.4
N-fert: CAN	kg N	96.7	142	78.1	6.4
N-fert: AS	kg N	12.3	10.4		3.39
Manure	kg N	29.5	50.5	23.0	64.8
P fert: TSP	kg P_2O_5	12.9	7.93	2.10	7.85
K fert: KCl	kg K_2O	32.2	10.4	9.72	10.3
Pesticides	kg a.i.	0.0950	0.10	0.095	0.095
Lorry	tkm	133	146	67.5	50.3
Diesel	MJ	2,415	2,415	2,415	2,415
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00
Services (per ha year)	p	1.00	1.00	1.00	1.00
Land tenure, arable	kg C	6,500	7,000	5,600	5,500
Emissions					
Dinitrogen monoxide (direct)	kg N_2O	5.05	6.27	3.87	4.54
Dinitrogen monoxide (indirect)	kg N_2O	1.38	1.67	0.995	1.10
Ammonia	kg NH_3	23.0	28.8	13.4	20.1
Nitrogen oxides	kg NO_x	7.16	8.97	4.18	6.25
Nitrate	kg NO_3	388	463	297	298

Roughage, maize ensilage

LCI of roughage, maize ensilage cultivation systems is presented in Table 5.55.

Table 5.55: LCI of roughage, maize ensilage cultivation. The data represent 1 ha year.

Parameters	Country: Unit	Roughage, maize ensilage			
		DE	DK	SE	UK
Output of products					
Determining product: Roughage	kg	29,507	35,813	28,463	28,139
Input of products					
N-fert: Ammonia	kg N		2.38		
N-fert: Urea	kg N	16.2	0.40		10.2
N-fert: AN	kg N		3.17	2.00	25.7
N-fert: CAN	kg N	28.7	32.5	26.3	4.15
N-fert: AS	kg N	3.64	2.38		2.21
Manure	kg N	60.8	102	34.5	38.7
P fert: TSP	kg P_2O_5	12.9	7.93	2.10	7.85
K fert: KCl	kg K_2O	32.2	29.1	9.72	10.3
Pesticides	kg a.i.	0.095	0.095	0.095	0.095
Lorry	tkm	57.7	48.6	26.7	37.0
Diesel	MJ	3,715	3,715	3,715	3,715
Capital goods (per ha year)	p	1.00	1.00	1.00	1.00
Services (per ha year)	p	1.00	1.00	1.00	1.00
Land tenure, arable	kg C	6,500	7,000	5,600	5,500
Emissions					
Dinitrogen monoxide (direct)	kg N_2O	3.66	5.04	2.90	2.82
Dinitrogen monoxide (indirect)	kg N_2O	0.876	1.16	0.684	0.686
Ammonia	kg NH_3	17.6	25.3	10.0	12.4
Nitrogen oxides	kg NO_x	5.47	7.87	3.13	3.85
Nitrate	kg NO_3	229	291	199	187

5.4 Parameters relating to switch between modelling assumptions

The allocation factors used for switching between the four modelling assumptions are presented in Table 5.56 and Table 5.57. The allocation factors are different from 2005-data, because the prices are different.

Table 5.56: Allocation factors used for allocation of products from barley and wheat cultivation. Unit: Fraction.

Allocation factors	Barley				Wheat			
	DE	DK	SE	UK	DE	DK	SE	UK
Switch 1: ISO 14040/44								
Determining product: Barley/wheat	1	1	1	1	1	1	1	1
Switch 2: Average/allocation								
Determining product: Barley/wheat	1	0.690	0.664	1	1	0.599	0.618	1
By-product at point of subst.: Elec DE/DK/SE/UK		0.111	0.106			0.143	0.121	
By-product at point of subst.: Distr. heat		0.200	0.229			0.258	0.261	
Switch 3: PAS2050								
Determining product: Barley/wheat	1	0.894	0.878	1	1	0.851	0.855	1
Material for treatment: Straw		0.106	0.122			0.149	0.145	
Switch 4: IDF								
Determining product: Barley/wheat	1	0.894	0.878	1	1	0.851	0.855	1
Material for treatment: Straw		0.106	0.122			0.149	0.145	

Table 5.57: Allocation factors used for allocation of products from oat and rapeseed cultivation. Unit: Fraction

Allocation factors	Oat				Rapeseed
	DE	DK	SE	UK	EU27
Switch 1: ISO 14040/44					
Determining product: Oat/rapeseed	1	1	1	1	1
Switch 2: Average/allocation					
Determining product: Oat/rapeseed	1	0.671	0.627	1	1
By-product at point of subst.: Elec DE/DK/SE/UK/EU27		0.118	0.118		
By-product at point of subst.: Distr. heat		0.212	0.255		
Switch 3: PAS2050					
Determining product: Oat/rapeseed	1	0.886	0.860	1	1
Material for treatment: Straw		0.114	0.140		
Switch 4: IDF					
Determining product Oat/rapeseed	1	0.886	0.860	1	1
Material for treatment: Straw		0.114	0.140		

6 The food industry system

6.1 Inventory of soybean meal system (soybean meal)

Data are obtained from Schmidt (2015). This publication contains LCI data in the same format as used in the current report.

6.2 Inventory of rapeseed oil system (rapeseed meal)

Data are obtained from Schmidt (2015). This publication contains LCI data in the same format as used in the current report.

6.3 Inventory of sunflower oil system (sunflower meal)

Data are obtained from Schmidt (2015). This publication contains LCI data in the same format as used in the current report.

6.4 Inventory of palm oil system (palm oil and palm kernel meal)

Data are obtained from Schmidt (2015). This publication contains LCI data in the same format as used in the current report.

6.5 Inventory of sugar system (molasses and beet pulp)

These data have been modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

6.6 Inventory of wheat flour system (wheat bran)

These data have been modelled for 2005 by Dalgaard and Schmidt (2012a). The same data have been applied here.

6.7 Parameters relating to switch between modelling assumptions

The allocation factors used for switching between the four modelling assumptions are presented from Table 6.1 to Table 6.5. They are different from 2005-data because prices from 2012 are used. For further details on prices, see Appendix C.

Table 6.1: Allocation factors related to products from the soybean meal system. Unit: Fraction.

Products	Soybean oil mill	Soybean oil refinery
	BR	BR
Switch 1: ISO 14040/44		
Determining product:		
Soybean meal	1	
Crude soybean oil for treatment		1
Switch 2: Average/allocation		
Determining product:		
Soybean meal	0.490	
Crude soybean oil for treatment		1.00
By-products at point of substitution:		
NBD oil	0.509	
Feed energy	0.00137	
Switch 3: PAS2050		
Determining product:		
Soybean meal	0.788	
By-products:		
Crude soybean oil for treatment	0.212	
NBD oil		0.990
FFA		0.00992
Switch 4: IDF		
Determining product:		
Soybean meal	0.788	
By-products:		
Crude soybean oil for treatment	0.212	

Table 6.2: Allocation factors related to products from the rapeseed oil system. Unit: Fraction.

Products	Rapeseed oil mill	Rapeseed oil refinery
	EU27	EU27
Switch 1: ISO 14040/44		
Determining product:		
Crude rapeseed oil	1	
NBD oil		1
Switch 2: Average/allocation		
Determining product:		
Crude rapeseed oil	0.726	
NBD oil		0.997
By-products at point of substitution:		
Feed energy	0.157	0.00308
Feed protein	0.117	
Switch 3: PAS2050		
Determining product:		
Crude rapeseed oil	0.744	
NBD oil		0.994
By-products		
Rapeseed meal	0.256	
FFA		0.00566
Switch 4: IDF		
Determining product:		
Crude rapeseed oil	0.744	
NBD oil		0.994
By-products:		
Rapeseed meal	0.256	
FFA		0.00566

Table 6.3: Allocation factors related to products from the sunflower oil system. Unit: Fraction.

Products	Sunflower oil mill
	FR
Switch 1: ISO 14040/44	
Determining product:	
Crude sunflower oil	1
Switch 2: Average/allocation	
Determining product:	
Crude sunflower oil	0.702
By-products at point of substitution:	
Feed energy	0.150
Feed protein	0.148
Switch 3: PAS2050	
Determining product:	
Crude sunflower oil	0.845
By-products:	
Utilisation of sunflower meal as feed	0.155
Switch 4: IDF	
Determining product:	
Crude sunflower oil	0.845
By-products:	
Utilisation of sunflower meal as feed	0.155

Table 6.4: Allocation factors related to products from the sugar system. Unit: Fraction.

Products	Sugar mill			
	DE	DK	SE	UK
Switch 1: ISO 14040/44				
Determining product:				
Sugar	1	1	1	1
Switch 2: Average/allocation				
Determining product:				
Sugar	0.879	0.867	0.867	0.882
By-products at point of substitution:				
Feed energy	0.0944	0.104	0.104	0.0920
Feed protein	0.0262	0.0290	0.0289	0.0255
Switch 3: PAS2050				
Determining product:				
Sugar	0.886	0.861	0.862	0.875
By-products:				
Molasses (74% DM)	0.0485	0.0480	0.0461	0.414
Beet pulp, dried (89.4% DM)	0.0656	0.0909	0.0916	0.836
Switch 4: IDF				
Determining product:				
Sugar	0.886	0.861	0.862	0.875
By-products:				
Molasses (74% DM)	0.0485	0.0480	0.0461	0.0414
Beet pulp, dried (89.4% DM)	0.0656	0.0909	0.0916	0.0836

Table 6.5: Allocation factors related to products from the wheat flour system. Unit: Fraction.

Products	Flour mill EU27
Switch 1: ISO 14040/44	
Determining product:	
Flour	1
Switch 2: Average/allocation	
Determining product:	
Flour	0.889
By-products at point of substitution:	
Feed energy	0.0728
Feed protein	0.0379
Switch 3: PAS2050	
Determining product:	
Flour	0.892
By-products:	
Wheat bran	0.108
Switch 4: IDF	
Determining product:	
Flour	0.892
By-products:	
Wheat bran	0.108

7 Life cycle impact assessment (LCIA)

In this chapter, the results for German, Danish, Swedish and British milk produced in 2012 are presented. GHG emissions are presented using the global warming potential (GWP100) from IPCC (2013). Previous reports on national milk baselines published by Arla Foods are based on an older version of IPCC's GWP100 (IPCC 2007), and the results are therefore not directly comparable to the results presented here. The most important differences are that the characterization factor for N_2O is decreased from 298 to 265 kg CO_2-eq./kg N_2O, and the characterization factor for CH_4 is increased from 25 to 28 kg CO_2-eq./kg CH_4.

The results for 2012 are presented together with results of milk produced in 1990 in Germany, Denmark, Sweden and United Kingdom. The Life Cycle Inventories representing milk production in 1990 are documented in De Rosa et al. (2013) and Dalgaard and Schmidt (2012b). It should be noted that the results for 1990 presented here are slightly different because newer emission factors are used (as described above)

7.1 Key performance indicators

Animal stocks and production volumes

The stock sizes and amount of milk and beef produced in the Germany, Denmark, Sweden and United Kingdom are presented in Table 7.15 and Table 7.16. The stock sizes have decreased from 1990 to 2012 in all four countries. The amount of milk ex farm produced has decreased in Germany, Sweden ad United Kingdom, whereas Denmark is the only countries where the milk production has increased.

Table 7.1: Size and production volumes of the milk systems in Germany and Denmark in 1990 and 2012.

Indicator	Unit	Germany		Denmark	
		1990	2012	1990	2012
Stock					
Cows	million heads	6.4	4.2	0.75	0.59
Heifers	million heads	6.7	4.4	0.82	0.56
Bull calves	million heads	0.23	0.29	0.037	0.048
Young bulls	million heads	2.0	1.1	0.34	0.17
Milk and beef production					
Milk ex farm	million tonne	29.9	29.7	4.54	4.92
Beef ex farm	million tonne	1.40	1.10	0.20	0.22

Table 7.2: Size and production volumes of the milk systems in Sweden and United Kingdom in 1990 and 2012.

Indicator	Unit	Sweden		United Kingdom	
		1990	2012	1990	2012
Stock					
Cows	million heads	0.58	0.35	2.87	1.81
Heifers	million heads	0.63	0.36	3.16	1.48
Bull calves	million heads	0.038	0.021	0.11	0.080
Young bulls	million heads	0.42	0.24	0.98	1.40
Milk and beef production					
Milk ex farm	million tonne	3.43	2.84	14.8	13.8
Beef ex farm	million tonne	0.25	0.14	0.88	0.80

Feed use

The feed used per dairy cow per year is presented in Table 7.3 and Table 7.4. The feed consumed by the offspring is also included.

Table 7.3: Feed use for the milk systems in Germany and Denmark in 1990 and 2012.

Indicator	Unit	Germany 1990	Germany 2012	Denmark 1990	Denmark 2012
Feed used for dairy cows including offspring					
Barley	kg/head/year	1,332		1,686	1,310
Wheat	kg/head/year		80		
Oat	kg/head/year			7,511	
Corn	kg/head/year	67	343	76	65.8
Soybean meal	kg/head/year	479	638	415	463
Rapeseed meal	kg/head/year	508	748	579	500
Sunflower meal	kg/head/year	398		454	392
Beet pulp, dried	kg/head/year	148		168	145
Beet pulp	kg/head/year				
Molasses	kg/head/year	49	194	56	48
Palm oil	kg/head/year	38		43	38
Palm kernel meal	kg/head/year		172		
Wheat bran	kg/head/year	46	451	53	46
Malt sprouts	kg/head/year		165		
Brewer's grain	kg/head/year				
DDGS	kg/head/year				8
Milk replacer	kg/head/year				
Feed urea	kg/head/year	10		11	12
Minerals, salts etc	kg/head/year	15	42	17	19
Fodder beets	kg/head/year				
Permanent grass	kg/head/year	701	1,080	798	903
Maize ensilage	kg/head/year	9,580	11,157	3,161	8,367
Rotation grass	kg/head/year	3,652	7,665	6,341	11,672
Total	**kg/head/year**	**17,022**	**22,735**	**21,370**	**23,988**

Table 7.4: Feed use for the milk systems in Sweden and United Kingdom in 1990 and 2012.

Indicator	Unit	Sweden 1990	Sweden 2012	United Kingdom 1990	United Kingdom 2012
Feed used for dairy cows including offspring					
Barley	kg/head	999	681	833	1,203
Wheat	kg/head	361	223	833	728
Oat	kg/head	1,087	472		
Corn	kg/head		12		
Soybean meal	kg/head	207	485	476	154
Rapeseed meal	kg/head	186	502	476	605
Sunflower meal	kg/head			476	121
Beet pulp, dried	kg/head				151
Beet pulp	kg/head	290	287		
Molasses	kg/head		59		
Palm oil	kg/head	26	160		
Palm kernel meal	kg/head	172	153		
Wheat bran	kg/head	121	162		
Malt sprouts	kg/head				
Brewer's grain	kg/head				
DDGS	kg/head				
Milk replacer	kg/head				
Feed urea	kg/head			10	
Minerals, salts etc	kg/head	30	104	15	142
Fodder beets	kg/head				
Permanent grass	kg/head	5,717	6,317	860	4,392
Oat/Maize ensilage	kg/head	5,787	1,397	10,181	5,242
Rotation grass	kg/head	10,772	14,226	3,153	14,815
Total	**kg/head**	**25,756**	**25,240**	**17,313**	**27,553**

Cattle production efficiencies

Data on cattle production efficiencies are presented in Table 7.5 and Table 7.6. Heifers per cow have decreased from 1990 to 2012 in all four countries. An important reason for this decrease is that the heifers are were older at first calving in 1990 compared to 2012. The milk (ECM) production per dairy cow per year have increased in all four countries, with the largest increased in Germany (52%) and the smallest increase in Sweden and Denmark (37%). The amount of beef produced per kg ECM has decreased in all countries, and it indicates, that the beef production not has increased with the same pace from 1990 to 2012 as the the milk production. The feed efficiencies have increased from 1990 to 2012 in Germany, Denmark and Sweden, but is almost kept at the same level in United Kingdom.

Table 7.5: Cattle production indicators for the milk systems in Germany and Denmark in 1990 and 2012.

Indicator	Unit	Germany 1990	Germany 2012	Denmark 1990	Denmark 2012
Cattle production efficiencies					
Heifers per cow	factor	1.06	1.05	1.09	0.96
Age, first calving	months	34.7	30.0	28.6	25.5
Replacement rate	%	28	29	37	38
Milk per head ex farm	kg/head/year	4,710	7,089	6,031	8,372
Milk (ECM) per head ex farm	kg ECM/head	4,730	7,202	6,334	8,704
Beef produced	g live weight/kg ECM	76.5	57.2	62.0	43.3
Fat in milk	%	4.09	4.13	4.43	4.28
Protein in milk	%	3.32	3.41	3.38	3.48
Feed efficiency	kg DM/kg ECM	1.38	1.18	1.15	1.05

Table 7.6: Cattle production indicators for the milk systems in Sweden and United Kingdom in 1990 and 2012.

Indicator	Unit	Sweden		United Kingdom	
		1990	2012	1990	2012
Cattle production efficiencies					
Heifers per cow	factor	1.09	1.03	1.10	0.82
Age, first calving	months	28.1	26.0	34.8	24.0
Replacement rate	%	38	40	29	24
Milk per head ex farm	kg/head/year	5,954	8,222	5,154	7,642
Milk (ECM) per head ex farm	kg ECM/head	6,157	8,451	5,082	7,620
Beef produced	g live weight/kg ECM	71.8	48.1	60.6	57.6
Fat in milk	%	4.31	4.22	4.01	4.07
Protein in milk	%	3.36	3.42	3.21	3.26
Feed efficiency	kg DM/kg ECM	1.42	1.06	1.30	1.31

Crop cultivation

Crop production indicators are presented in Table 7.7 and Table 7.8. There is a clear tendency showing that crops yields are have increased while the amount of fertiliser per hectare has decreased.

Table 7.7: Crop production indicators for Germany and Denmark in 1990 and 2012.

Indicator	Unit	Germany		Denmark	
		1990	2012	1990	2012
Crop yields					
Barley	t/ha/year	5.1	6.1	4.7	5.4
Wheat	t/ha/year	6.2	7.4	6.7	7.1
Permanent grass	t/ha/year	6.0	6.0	11.1	11.6
Rotation grass	t/ha/year	19.4	19.5	22.6	23.6
Maize ensilage	t/ha/year	29.4	29.5	34.3	35.8
Fertiliser (mineral + manure)					
Barley	kg N/ha/year	135	193	151	109
Wheat	kg N/ha/year	205	212	230	155
Permanent grass	kg N/ha/year	206	131	231	66
Rotation grass	kg N/ha/year	373	193	419	228
Maize ensilage	kg N/ha/year	168	109	189	143

Table 7.8: Crop production indicators for Sweden and United Kingdom in 1990 and 2012.

Indicator	Unit	Sweden		United Kingdom	
		1990	2012	1990	2012
Crop yields					
Barley	t/ha/year	3.8	4.4	5.2	5.6
Wheat	t/ha/year	5.6	5.9	6.9	7.4
Permanent grass	t/ha/year	8.9	9.3	8.5	9.1
Rotation grass	t/ha/year	21.9	22.9	17.2	18.6
Maize ensilage	t/ha/year	28.1	28.5	26.1	28.1
Fertiliser (mineral + manure)					
Permanent grass	kg N/ha/year	88	107	225	76
Rotation grass	kg N/ha/year	167	73	407	130
Oat/Maize ensilage	kg N/ha/year	116	135	184	81
Barley	kg N/ha/year	116	107	147	160
Wheat	kg N/ha/year	116	63	223	253

7.2 Overall results

The overall results four each of the four switches are presented in Figure 7.1, Figure 7.2, Figure 7.3 and Figure 7.4. The carbon footprints of milk have decreased from 1990 to 2012 regardless of the applied switch mode.

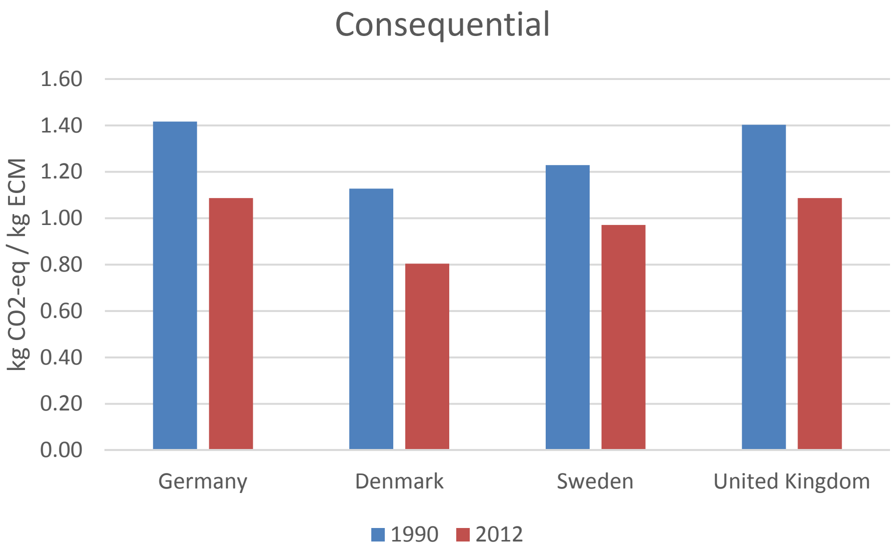

Figure 7.1: Carbon footprint for milk produced in 1990 and 2012. Model: Consequential incl. capital goods, services and iLUC.

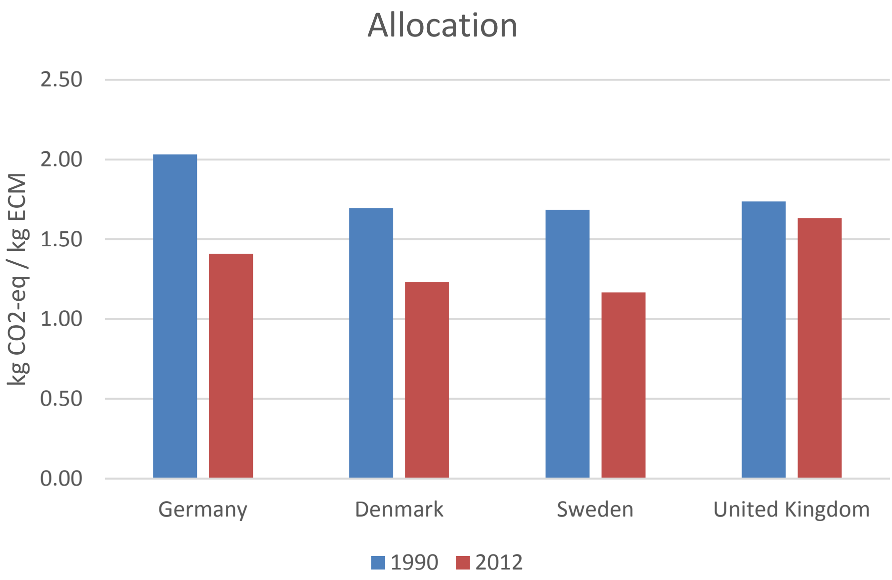

Figure 7.2: Carbon footprint for milk produced in 1990 and 2012. Model: Allocation incl. capital goods, services and iLUC.

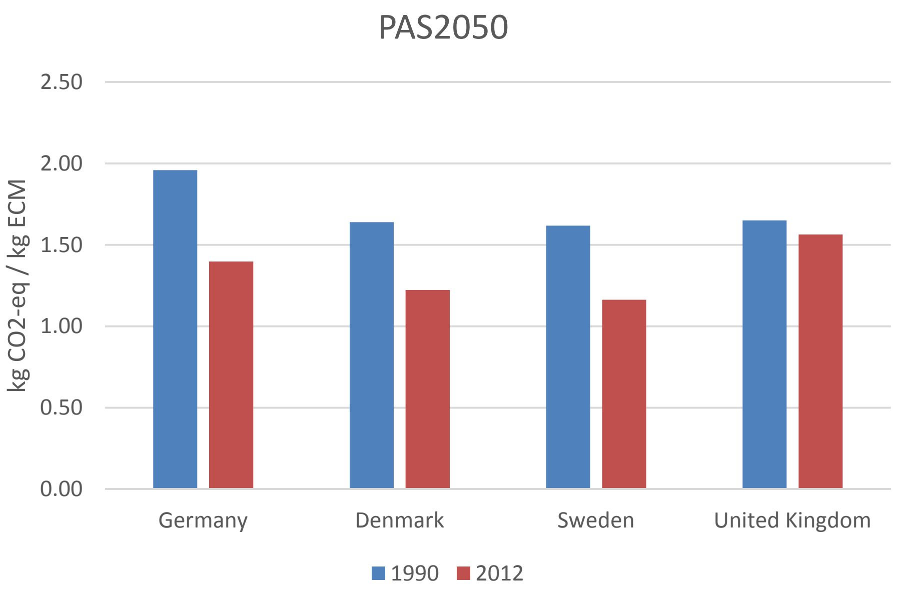

Figure 7.3: Carbon footprint for milk produced in 1990 and 2012. Model: PAS2050 including capital goods, excluding services and iLUC.

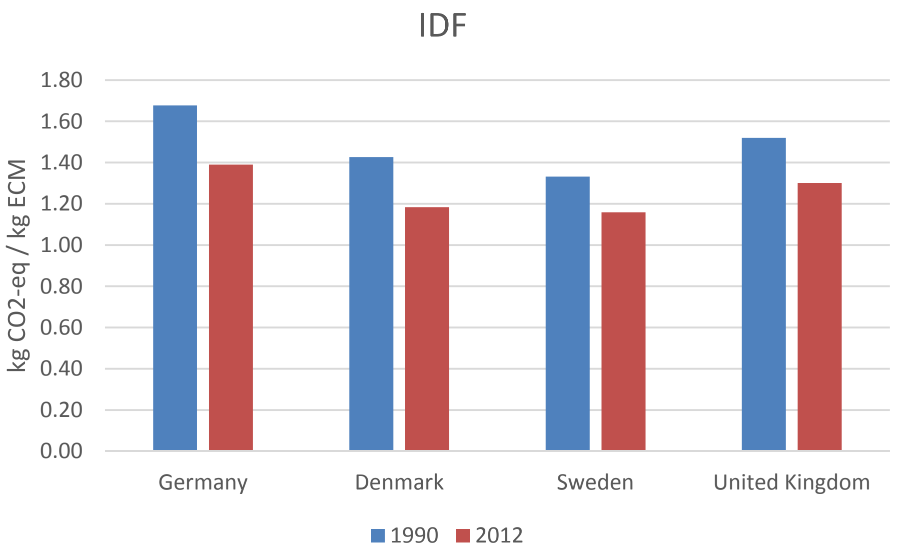

Figure 7.4: Carbon footprint for milk produced in 1990 and 2012. Model: IDF.

7.3 Detailed results: Germany

Consequential model

The detailed carbon footprint results are presented in Table 7.9.

Table 7.9: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Germany** in 1990 and 2012: **Consequential model**. Unit: kg CO_2-eq. per kg ECM.

Germany **Model: Consequential**	**1990**		**2012**		**Description**
Direct emissions from animal production					
CH_4 enteric fermentation	0.94		0.79		CH_4 from ent. ferm. is lower in 2012 due to increased feed efficiency (Table 6.5).
CH_4, manure handling and storage	0.11		0.16		
N_2O direct, manure handling and storage	0.06		0.06		
N_2O indirect, manure handling and storage	0.01	**1.11**	0.01	**1.02**	
Production of feed					
Roughage: permanent grass	0.11		0.09		The GHG-emission from production of feed is lower in 2012. This is caused by a higher feed efficiency in 2012 (Table 6.5), which means less feed is used per kg milk. Furthermore, the consumed feed is produced more efficiently, as shown in Table 6.7, where the tendency is higher yields.
Roughage: rotation grass	0.28		0.26		
Roughage: maize/barley-pea/oats whole crop ensilage	0.29		0.20		
Barley					
Oat					
Wheat			0.01		
Corn	0.01		0.02		
Soybean meal	-0.02		-0.02		
Rapeseed meal	0.01		0.001		
Palm kernel meal			0.004		
Sunflower meal	-0.02				
Wheat bran	0.00		0.01		
Sugar beet pulp	0.02				
Molasses	0.005		0.01		
Palm oil	0.03				
Other (feed urea and mineral feed)	0.01	**0.73**	0.01	**0.59**	
Other inputs					
Energy (fuels&combustion and electricity)	0.08		0.07		
Transport (of feed etc. to milk farm)	0.09		0.08		
Other (buildings, destruction of animals etc.)	0.10	**0.27**	0.09	**0.24**	
Materials for treatment/by-products					
Manure land application	0.24		0.001		Less beef is substituted per kg milk in 2012 (Table 6.5)
Beef	-1.54	**-1.30**	-1.14	**-1.14**	
Land					
Indirect land use changes (iLUC)	0.60	**0.60**	0.38	**0.38**	Less land is required per kg milk.
Total		**1.42**		**1.09**	

IDF model

The detailed carbon footprint results are presented in Table 7.10.

Table 7.10: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Germany** in 1990 and 2012: **IDF model**. Unit: kg CO_2-eq. per kg ECM.

Germany **Model: IDF**	**1990**		**2012**		**Description**
Direct emissions from animal production					
CH_4 enteric fermentation	0.62		0.54		
CH_4, manure handling and storage	0.07		0.11		
N_2O direct, manure handling and storage	0.04		0.04		
N_2O indirect, manure handling and storage	0.01	**0.73**	0.01	**0.70**	
Production of feed					
Roughage: permanent grass	0.07		0.06		
Roughage: rotation grass	0.18		0.18		
Roughage: maize/barley-pea/oats whole crop ensilage	0.16		0.14		
Barley	0.11				
Oat					
Wheat			0.005		
Corn	0.01		0.01		
Soybean meal	0.02		0.03		
Rapeseed meal	0.05		0.03		
Palm kernel meal	0.01		0.003		
Sunflower meal	0.05				
Wheat bran	0.00		0.02		
Sugar beet pulp	0.01				
Molasses	0.002		0.01		
Palm oil					
Other (feed urea and mineral feed)	0.01	**0.70**	0.01	**0.49**	
Other inputs					
Energy (fuels&combustion and electricity)	0.16		0.11		
Transport (of feed etc. to milk farm)	0.06		0.06		
Other (buildings, destruction of animals etc.)	0.03	**0.25**	0.04	**0.20**	
Materials for treatment/by-products					
Manure land application	0.003	0.003	0.003	0.003	
Total		**1.68**		**1.39**	

7.4 Detailed results: Denmark

Consequential model

The detailed carbon footprint results are presented in Table 7.11.

Table 7.11: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Denmark** in 1990 and 2012: **Consequential model**. Unit: kg CO_2-eq. per kg ECM.

Denmark **Model: Consequential**	**1990**		**2012**		**Description**
Direct emissions from animal production					
CH_4 enteric fermentation	0.77		0.70		
CH_4, manure handling and storage	0.10		0.13		
N_2O direct, manure handling and storage	0.04		0.05		
N_2O indirect, manure handling and storage	0.01	**0.92**	0.01	**0.89**	
Production of feed					
Roughage: permanent grass	0.05		0.02		
Roughage: rotation grass	0.27		0.22		
Roughage: maize/barley-pea/oats whole crop ensilage	0.05		0.07		
Barley	0.12		0.03		
Oat	0.09				
Wheat					
Corn	0.01		0.002		
Soybean meal	-0.01		-0.01		
Rapeseed meal	0.01		0.000		
Palm kernel meal					
Sunflower meal	-0.01		-0.01		
Wheat bran	0.003		0.001		
Sugar beet pulp	0.02		0.01		
Molasses	0.004		0.001		
Palm oil	0.02		0.02		
Other (feed urea and mineral feed)	0.01	**0.62**	0.01	**0.36**	
Other inputs					
Energy (fuels&combustion and electricity)	0.12		0.02		
Transport (of feed etc. to milk farm)	0.11		0.05		
Other (buildings, destruction of animals etc.)	0.08	**0.32**	0.05	**0.12**	
Materials for treatment/by-products					
Manure land application	0.04		-0.01		
Beef	-1.25	**-1.20**	-0.86	**-0.87**	
Land					
Indirect land use changes (iLUC)	0.47	**0.47**	0.31	**0.31**	
Total		**1.13**		**0.80**	

IDF model

The detailed carbon footprint results are presented in Table 7.12.

Table 7.12: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Denmark** in 1990 and 2012: **IDF model**. Unit: kg CO_2-eq. per kg ECM.

Denmark **Model: IDF**	**1990**		**2012**		**Description**
Direct emissions from animal production					
CH_4 enteric fermentation	0.52		0.55		
CH_4, manure handling and storage	0.07		0.10		
N_2O direct, manure handling and storage	0.03		0.04		
N_2O indirect, manure handling and storage	0.00	**0.62**	0.00	**0.69**	
Production of feed					
Roughage: permanent grass	0.03		0.01		
Roughage: rotation grass	0.18		0.17		
Roughage: maize/barley-pea/oats whole crop ensilage	0.03		0.06		
Barley	0.09		0.04		
Oat	0.06				
Wheat					
Corn	0.01		0.002		
Soybean meal	0.01		0.02		
Rapeseed meal	0.06		0.02		
Palm kernel meal					
Sunflower meal	0.04		0.01		
Wheat bran	0.002		0.001		
Sugar beet pulp	0.01		0.007		
Molasses	0.00		0.002		
Palm oil	0.01		0.01		
Other (feed urea and mineral feed)	0.005	**0.55**	0.005	**0.36**	
Other inputs					
Energy (fuels&combustion and electricity)	0.16		0.07		
Transport (of feed etc. to milk farm)	0.07		0.04		
Other (buildings, destruction of animals etc.)	0.02	**0.25**	0.01	**0.12**	
Materials for treatment/by-products					
Manure land application	0.003	0.003	0.003	**0.003**	
Total		1.43		**1.18**	

7.5 Detailed results: Sweden

Consequential model

The detailed carbon footprint results are presented in Table 7.13.

Table 7.13: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Sweden** in 1990 and 2012: **Consequential model**. Unit: kg CO_2-eq. per kg ECM.

Sweden **Model: Consequential**	1990		2012		Description
Direct emissions from animal production					
CH_4 enteric fermentation	0.95		0.71		
CH_4, manure handling and storage	0.08		0.09		
N_2O direct, manure handling and storage	0.05		0.04		
N_2O indirect, manure handling and storage	0.01	**1.08**	0.005	**0.84**	
Production of feed					
Roughage: permanent grass	0.41		0.21		
Roughage: rotation grass	0.20		0.19		
Roughage: maize/barley-pea/oats whole crop ensilage	0.07		0.01		
Barley	0.06		0.02		
Oat	0.07		0.02		
Wheat	0.02		0.00303		
Corn			0.0005		
Soybean meal	-0.01		-0.01		
Rapeseed meal	0.003		0.000		
Palm kernel meal	0.01		0.003		
Sunflower meal					
Wheat bran	0.01		0.003		
Sugar beet pulp	0.004		0.002		
Molasses			0.002		
Palm oil	0.01		0.09		
Other (feed urea and mineral feed)	0.01	**0.88**	0.02	**0.57**	
Other inputs					
Energy (fuels&combustion and electricity)	0.06		0.03		
Transport (of feed etc. to milk farm)	0.06		0.07		
Other (buildings, destruction of animals etc.)	0.09	**0.22**	0.06	**0.16**	
Materials for treatment/by-products					
Manure land application	0.04		0.01		
Beef	-1.44	**-1.40**	-0.96	**-0.95**	
Land					
Indirect land use changes (iLUC)	0.45	**0.45**	0.35	**0.35**	
Total		**1.23**		**0.97**	

IDF model

The detailed carbon footprint results are presented in Table 7.14.

Table 7.14: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Sweden** in 1990 and 2012: **IDF model**. Unit: kg CO_2-eq. per kg ECM.

Sweden **Model: IDF**	**1990**		**2012**		**Description**
Direct emissions from animal production					
CH_4 enteric fermentation	0.60		0.51		
CH_4, manure handling and storage	0.05		0.07		
N_2O direct, manure handling and storage	0.03		0.03		
N_2O indirect, manure handling and storage	0.01	**0.69**	0.004	**0.61**	
Production of feed					
Roughage: permanent grass	0.26		0.15		
Roughage: rotation grass	0.13		0.14		
Roughage: maize/barley-pea/oats whole crop ensilage	0.04		0.01		
Barley	0.04		0.02		
Oat	0.05		0.02		
Wheat	0.01		0.01		
Corn			0.0003		
Soybean meal	0.01		0.02		
Rapeseed meal	0.02		0.02		
Palm kernel meal	0.01		0.002		
Sunflower meal					
Wheat bran	0.003		0.004		
Sugar beet pulp	0.002		0.002		
Molasses			0.002		
Palm oil	0.01		0.05		
Other (feed urea and mineral feed)	0.01	**0.57**	0.02	**0.46**	
Other inputs					
Energy (fuels&combustion and electricity)	0.02		0.02		
Transport (of feed etc. to milk farm)	0.04		0.05		
Other (buildings, destruction of animals etc.)	0.02	**0.08**	0.02	**0.09**	
Materials for treatment/by-products					
Manure land application	0.003	0.003	0.002	**0.002**	
Total		**1.33**		**1.16**	

7.6 Detailed results: United Kingdom

Consequential model

The detailed carbon footprint results are presented in Table 7.15.

Table 7.15: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **Unite Kingdom** in 1990 and 2012: **Consequential model**. Unit: kg CO_2-eq. per kg ECM.

United Kingdom Model: Consequential	1990		2012		Description
Direct emissions from animal production					
CH_4 enteric fermentation	0.88		0.86		
CH_4, manure handling and storage	0.05		0.10		
N_2O direct, manure handling and storage	0.03		0.04		
N_2O indirect, manure handling and storage	0.01	**0.97**	0.01	**1.01**	
Production of feed					
Roughage: permanent grass	0.09		0.14		
Roughage: rotation grass	0.23		0.30		
Roughage: maize/barley-pea/oats whole crop ensilage	0.30		0.06		
Barley	0.11		0.08		
Oat					
Wheat	0.10		0.05		
Corn					
Soybean meal	-0.02		-0.005		
Rapeseed meal	0.01		0.001		
Palm kernel meal					
Sunflower meal	-0.02		0.00		
Wheat bran					
Sugar beet pulp			0.01		
Molasses					
Palm oil					
Other (feed urea and mineral feed)	0.01	**0.81**	0.04	**0.68**	
Other inputs					
Energy (fuels&combustion and electricity)	0.07		0.05		
Transport (of feed etc. to milk farm)	0.08		0.03		
Other (buildings, destruction of animals etc.)	0.10	**0.25**	0.07	**0.15**	
Materials for treatment/by-products					
Manure land application	0.07		0.04		
Beef	-1.22	**-1.15**	-1.14	**-1.11**	
Land					
Indirect land use changes (iLUC)	0.52	0.52	0.36	0.36	
Total		**1.40**		**1.09**	

IDF model

The detailed carbon footprint results are presented in Table 7.16.

Table 7.16: Comparison of the GHG-emissions from 1 kg energy corrected milk (ECM) in **United Kingdom** in 1990 and 2012: **IDF model**. Unit: kg CO_2-eq. per kg ECM.

United Kingdom Model: IDF	1990		2012		Description
Direct emissions from animal production					
CH_4 enteric fermentation	0.62		0.58		
CH_4, manure handling and storage	0.04		0.07		
N_2O direct, manure handling and storage	0.02		0.03		
N_2O indirect, manure handling and storage	0.005	**0.68**	0.005	**0.68**	
Production of feed					
Roughage: permanent grass			0.09		
Roughage: rotation grass	0.16		0.21		
Roughage: maize/barley-pea/oats whole crop ensilage	0.18		0.04		
Barley	0.06		0.05		
Oat					
Wheat	0.06		0.03		
Corn					
Soybean meal	0.02		0.01		
Rapeseed meal	0.04		0.02		
Palm kernel meal					
Sunflower meal	0.06		0.00		
Wheat bran					
Sugar beet pulp			0.01		
Molasses					
Palm oil					
Other (feed urea and mineral feed)	0.06	**0.66**	0.02	**0.48**	
Other inputs					
Energy (fuels&combustion and electricity)	0.10		0.10		
Transport (of feed etc. to milk farm)	0.05		0.02		
Other (buildings, destruction of animals etc.)	0.03	**0.18**	0.02	**0.14**	
Materials for treatment/by-products					
Manure land application	0.002	**0.002**	0.002	**0.002**	
Total		**1.52**		**1.30**	

8 Uncertainties

The model and data uncertainties for milk production in Denmark and Sweden in 2005 are evaluated in Schmidt and Dalgaard (2012). Since the current study uses the same model and the same type of data, a new sensitivity analysis is not carried out. The outcome of the sensitivity analysis from Schmidt and Dalgaard (2012) is summarised below:

Model uncertainties: The model is fully parameterised, so it can be seen as an empty shell that only makes sense when it is filled with input parameters (from the inventory report or farm specific data). The model framework is highly flexible and can handle most changes in assumptions regarding modelling of co-product allocation, market mixes, completeness and land use changes. The model uncertainties are mainly related to the applied emission models. Most of these are adopted from IPCC (2006). Emission factors and models from IPCC are characterised by being applicable to all countries and crop/animal types, which makes the choice of emission models very consistent and comparable across crops and animals in different parts of the world. This is an important feature since the milk system potentially affects production processes in many parts of the world. On the other hand, the IPCC models are sometimes not fully adjusted to local conditions and they have not enough level of detail for capturing all relevant aspects. In general, the applied emission models are regarded as being related to some uncertainties, but at the same time they also allow for comparison across geographical locations and different crops and animals.

Data uncertainties: For the national baselines, the most important assumptions relate to the animal turnover, the feed composition, the identification of substituted beef system (only ISO 14040/44 switch) and indirect land use changes model. The collected data on animal turnover and feed composition are regarded as being related to a low degree of uncertainty. The identification of Brazilian beef as the substituted beef system is associated with significant uncertainties. The effect of this has been tested in Schmidt and Dalgaard (2012, chapter 11.1), where it appears that the results are sensitive to the identification of the beef system. The uncertainties related to land use changes are also significant. In Schmidt et al. (2015) the major sources of uncertainty are related to the proportion between yield increases and land transformation, and to the modelling of yield increases which are modelled assuming only additional fertiliser as a flexible mean of increasing yields. Also, the data regarding the potential net primary production (NPP_0) in the included countries is associated with uncertainties since this is based on a relatively course grained global map from Haberl et al. (2007).

The uncertainties related to the applied switch modes available in the study are mainly related to the methodological problems with the switches for:

- Average/allocation attributional
- PAS2050
- IDF

The problems for these switch modes include:

- Lack of cause-effect relationships, e.g. when constrained suppliers are included in the inventoried system, see Schmidt (2010a) and Weidema et al (2009)
- Allocated processes do not fulfil the mass balance principle (when inputs are allocated in another unit than their mass, the mass balance will be lost), see Weidema and Schmidt (2010).
- The exclusion of capital goods and/or services leads to incomplete results, and potentially comparisons may be misleading if the compared systems are related to different emissions from these input categories.

The modelling of land use changes in the average/allocation attributional switch mode underestimates the impact, because the attributional scenario in Schmidt et al. (2015) includes constrained supplies of land, i.e. land already in use. The modelling of land use changes in the PAS2050 and IDF switch modes focuses on the direct land use changes in a historical perspective. This means that the sourcing of a crop from a field, which has been transformed from forest within the latest 20 years contributes to DLUC, whereas no other land occupation causes DLUC. This approach misses a cause-effect relationship and it allocates LUC emissions to crops on recently transformed land, which may not contribute more to LUC than other crops.

9 Sensitivity, completeness and consistency checks

According to ISO 14044 (2006) an evaluation in the interpretation phase including sensitivity, completeness and consistency check must be carried out in order to establish confidence in the results of the LCA. The sensitivity, completeness and consistency checks presented in the following are very similar to the ones presented in Schmidt and Dalgaard (2012) for the LCA of milk production in Denmark and Sweden in 2005. This is because the current study uses the same model and the same type of data as Schmidt and Dalgaard (2012).

9.1 Sensitivity check

The objective of the sensitivity check is to assess the reliability of the results and how they are affected by system boundaries, uncertainties in data, assumptions and LCIA-methods (ISO 14044 2006).

System boundaries/the model: The approach to system delimitation (different switch modes) significantly affects the results as demonstrated in **chapter 7**. The included switches enables for using system wide different ways of modelling co-producing activities, market mixes (including or excluding constrained suppliers), and applying different levels of completeness (including/excluding capital goods, services and land use changes).

In **chapter 8**, the major source of uncertainty relating to the model is identified as the inherent uncertainties related to the applied emission models from IPCC. The choice of these models relies on a compromise to be able to consistently us the same models throughout the study for all regions and crops/animals whereas more country specific models may be related to smaller levels of uncertainty.

Uncertainty in data: In **chapter 8**, the most critical uncertainties in data are identified as the ones relating to the animal turnover (incl. animals weights), feed composition, identification of the substituted beef system and the data used for the modelling of indirect land use changes.

LCIA-method: The IPCC GWP100 method is used. This method weight the relative importance of different GHG-emissions (CO_2, N_2O, CH_4 etc.) based on a time horizon of 100 years. Some effects related to global warming have impacts which relevant in a shorter short time frame than 100 years (e.g. extreme weather) while other impacts are more relevant for the longer term (e.g. increases in sea level). Therefore, ideally GHG-emissions should be assessed using different indicators representing different impacts. However, such indicators are not immediately available and widely accepted. Therefore, the current study only uses GWP100, which currently is the most accepted and widely used indicator for GHG-emissions.

9.2 Completeness check

The objective of a completeness check is to ensure that the information provided in the difference phases of the LCA are sufficient in order to interpret the results (ISO 14044 2006).

The life cycle inventory consistently operates with a cut-off criterion at 0% for the consequential model (ISO 14040/44) and by excluding services for the IDF switch.

9.3 Consistency check

The objective of the consistency check is to verify that assumptions, methods and data are consistent with the goal and scope. Especially the consistency regarding data quality along the product chain, regional/temporal differences, allocation rules/system boundaries and LCIA are important (ISO 14044).

In general, the model is based on a very consistent and well-defined methodological framework as presented in Schmidt and Dalgaard (2012). This framework and data enables for consistently and system wide applying different modelling assumptions and levels of completeness in the inventory.

The applied emissions models for direct emissions in agriculture from animals and crop cultivation are all based on IPCC (2006).

Inventory data for upstream activities are partly based on ecoinvent (2010) and the EU27 IO-database (available in SimaPro 8). Country specific and modelling switch specific electricity is applied in the agricultural activities (animal and crop) and the food industry activities.

Upstream activities for transport, materials, fuels and energy are based on ecoinvent and the related standard technology average mixes and allocated processes.

Upstream activities for services are based on the EU27 IO-database, which uses a higher degree of completeness, allocation is avoided by substitution and EU27 market mixes are generally applied.

The combination of ecoinvent and the EU27 IO-database is inconsistent. However, the contribution from the activities in these databases is very limited compared to the direct emissions from animals and crop cultivation as well as the emissions from land use changes.

In general, the study is regarded as having a very high degree of consistency.

10 Conclusion

This report presents a detailed LCI of milk production in Germany, Denmark, Sweden and United Kingdom in 2012. LCIA results are presented for 2012 and 1990. The LCIs for 1990 are documented in Dalgaard and Schmidt (2012b) and De Rosa et al. (2013). The overall results are presented using four different modelling assumptions: consequential (ISO 14040/44), average/allocation, PAS2050, and IDF. Detailed data are presented using the consequential and the IDF modelling approach.

The national baselines are used by Arla Foods to benchmark milk production over time and farm specific data. The inventories are also used as background data in Arla Foods farm GHG calculator.

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Appendix A: Fuel and substance properties

Appendix table 1: Densities are from Andersen et al. (1981, p 119, 218) and for methane UN CDM project no 1153 (2006). Calorific values (lower heating value) are from NERI (2010, p 639-640).

Fuel	Density	Energy content	
Fuel oil	0.95 tonne/m^3	40.7 MJ/kg	38.6 MJ/litre
Diesel	0.87 tonne/m^3	42.7 MJ/kg	36.4 MJ/litre
Motor Gasoline	0.72 tonne/m^3	43.8 MJ/kg	30.8 MJ/litre
Natural gas	0.80 tonne/m^3	49.6 MJ/kg	39.7 MJ/litre
Hard coal (not for electricity plant)	-	26.5 MJ/kg	-
Methane	0.713 kg/ m^3	50.2 MJ/kg	35.8 MJ/Nm^3

Appendix table 2: Molar masses of substances.

Substances/material	Molar mass, M (g/mol)
Hydrogen (H)	1
Carbon (C)	12
Nitrogen (N)	14
Oxygen (O)	16
Phosphorus (P)	31
Sulphur (S)	32
Potassium (K)	39

Appendix B: Feed and crop properties

Appendix table 3: Feed characteristics. Feed code refers to the feed code (Danish: Foderkode) in Møller et al. (2005).

Feed:		Barley	Wheat	Oat	Corn	Soybean meal	Rapeseed cake/meal	Sunflower meal	Beet pulp, dried	Fodder beet	Molasses, beet	Palm oil	Palm kernel meal	Wheat bran	Feed urea	Minerals, salt etc.	Permanent grass	Maize silage	Oats whole crop ensilage	Rotation grass
Feed code:	Unit	201	203	202	204	154	144	165	283	351	277	347	136	232	760		458	**	586 ***	425
Input parameters																				
Dry matter content	kg DM/kg	0.850	0.850	0.850	0.875	0.874	0.889	0.890	0.894	0.18	0.740	0.990	0.906	0.871	1	1	0.180	0.33	0.340	0.38
Raw protein	kg/kg DM	0.108	0.115	0.102	0.096	0.535	0.35	0.417	0.096	0.074	0.130	0	0.170	0.183	2.28	0	0.200	0.079	0.105	0.160
Raw fat	kg/kg DM	0.031	0.024	0.053	0.046	0.028	0.105	0.030	0.012	0.4	0.001	1	0.082	0.046	0	0	0.039	0.022	0.025	0.044
Carbohydrate	kg/kg DM	0.838	0.842	0.819	0.843	0.361	0.475	0.467	0.822	0.842	0.742	0	0.707	0.713	0	0	0.661	0.863	0.794	0.699
Ash	kg/kg DM	0.023	0.018	0.026	0.015	0.076	0.07	0.086	0.07	0.080	0.127	0	0.041	0.058	1	1	0.100	0.036	0.076	0.097
Digestible energy	MJ/kg DM	15.2	16.0	13.4	16.2	18.0	16.2	15.1	14.6	14.0	13.6	32.2	12.8	13.1	0	0	13.2	13.3	11.0	13.2
Feed energy content	SFU/kg DM	1.11	1.21	0.91	1.22	1.40	1.19	1.07	1.00	0.99	0.98	2.82	0.83	0.89	0	0	0.86	0.88	0.62	0.85
Calculated parameters																				
Gross energy	MJ/kg DM	19.2	19.2	19.5	19.6	20.6	21.1	19.8	18.0	17.5	16.9	36.6	20.2	19.3	0	0	18.5	18.7	18.1	18.4
Digestible energy *	MJ/MJ	0.79	0.83	0.69	0.83	0.87	0.77	0.76	0.81	0.80	0.80	0.88	0.63	0.68	0	0	0.71	0.71	0.67	0.72
Feed energy (net energy)	MJ/kg DM	8.68	9.46	7.12	9.54	10.95	9.31	8.37	7.82	7.74	7.66	22.05	6.49	6.96	0	0	6.73	6.88	4.85	6.62

*expressed as a percentage of gross energy

** Bligaard (2013b)

*** Used in the Swedish model instead of Maize ensilage.

Appendix C: Prices

C.1 Cattle system

Cattle system					
Prices	**Unit**	**DK**	**DE**	**SE**	**UK**
Milk (ECM)	EUR2012 kg ECM milk-1	0.351	0.324	0.394	0.341
Meat live weight	EUR2012 kg live weight-1	1.95	2.40	3.16	1.34
Live animal: cow	EUR2012 kg head-1	1,094	1,279	1,084	1,082
Live animal: heifer	EUR2012 kg head-1	628	743	663	718
Live animal: small bull	EUR2012 kg head-1	576	928	780	770
Live animal: bull	EUR2012 kg head-1	576	928	780	770
Dead animal	EUR2012 kg live weight-1	0	0	0	0
Ammonium nitrate, as N	EUR2012 kg N-1	0.857	1.07	1.13	0.955
Triple superphosphate, as P2O5	EUR2012 kg P2O5-1	0.614	0.874	0.896	0.861
Potassium chloride, as K2O	EUR2012 kg K2O-1	0.714	0.549	0.594	0.603
Electricity	EUR2012 kWh electricity-1	0.0823	0.117	0.0704	0.107
Heat	EUR2012 MJ heat-1	0.0278	0.0203	0.0206	0.00495
Coal	EUR2012 MJ-1	0.00383	0.00390	0.00383	0.00339
Fuel oil	EUR2012 MJ-1	0.0178	0.0195	0.0192	0.0194

Cattle system				
Data sources	**DK**	**DE**	**SE**	**UK**
Milk (ECM)	Production price (DK): 'Milk, whole fresh cow'. FAOSTAT (2014), FAOSTAT annual producer prices. http://faostat.fao.org/ (Accessed 07/10/2014)	Production price (DE): 'Milk, whole fresh cow'. FAOSTAT (2014), FAOSTAT annual producer prices. http://faostat.fao.org/ (Accessed 07/10/2014)	Production price (SE): 'Milk, whole fresh cow'. FAOSTAT (2014), FAOSTAT annual producer prices. http://faostat.fao.org/ (Accessed 03/03/2015)	Production price (UK): 'Milk, whole fresh cow'. FAOSTAT (2014), FAOSTAT annual producer prices. http://faostat.fao.org/ (Accessed 03/03/2015)
Meat live weight	Export price (DK): 'Meat, cattle'. FAOSTAT (2014), Export price of 'meat, cattle' corrected with the dressing percentage (0.6) (due to lack of data of production price). http://faostat.fao.org/ The dressing percentage: FAO (Food and Agriculture Organization of the United Nations, 1991) Guidelines for slaughtering, meat cutting and further processing, Rome (http://www.fao.org/docrep/004/T0279E/T0279E00.htm "Beef cutting") (Both accessed 07/10/2014)	Export price (DE): 'Meat, cattle'. FAOSTAT (2014), Export price of 'meat, cattle' corrected with the dressing percentage (0.55) (due to lack of data of production price). Export value/Export quantity. http://faostat.fao.org/ The dressing percentage: FAO (Food and Agriculture Organization of the United Nations), 1991. Guidelines for slaughtering, meat cutting and further processing, Rome (http://www.fao.org/docrep/004/T0279E/T0279E00.htm "Beef cutting") (Both accessed 07/10/2014)	Export price, 2011 (SE): 'Meat, cattle'. FAOSTAT (2014), Export price of 'meat, cattle' corrected with the dressing percentage (0.6) (due to lack of data of production price). http://faostat.fao.org/ The dressing percentage: FAO (Food and Agriculture Organization of the United Nations, 1991) Guidelines for slaughtering, meat cutting and further processing, Rome (http://www.fao.org/docrep/004/T0279E/T0279E00.htm "Beef cutting") (Both accessed 07/10/2014)	Export price (UK): 'Meat, cattle'. FAOSTAT (2014), Export price of 'meat, cattle' corrected with the dressing percentage (due to lack of data for production price). http://faostat.fao.org/ The dressing percentage: 0.48 Annexes to National Inventory Report (Webb et al. 2014b) (Both accessed 03/03/2015)
Live animal: cow	Market price (DK), average of 12 months: 'Bovine, cows'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DE), average of 12 months: 'Bovine, cows'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (SE), average of 12 months: 'Bovine, cows'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (UK), average of 12 months: 'Bovine, cows'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)
Live animal: heifer	Market price (DK), average of 12 months: 'Bovine, heifers'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DE), average of 12 months: 'Bovine, heifers'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (SE), average of 12 months: 'Bovine, heifers'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DK), average of 12 months: 'Bovine, heifers'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)

Live animal: small bull	Market price (DK), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DE), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (SE), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DK), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)
Live animal: bull	Market price (DK), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DE), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (SE), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)	Market price (DK), average of 12 months: 'Bovine, young bulls'. European Commission (2015), Agriculture and Rural Development, Price monitoring. http://ec.europa.eu/agriculture/markets-and-prices/price-monitoring/index_en.htm (Accessed 14/01/2015)
Dead animal	Dead animals for destruction are not paid for by destruction industry	Dead animals for destruction are not paid for by destruction industry	Dead animals for destruction are not paid for by destruction industry	Dead animals for destruction are not paid for by destruction industry
Ammonium nitrate, as N	Import price (DK): 'Ammonium nitrate, including solution, in pack >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 07/10/2014)	Import price (DE): 'Ammonium nitrate, including solution, in pack >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 07/10/2014)	Import price (SE): 'Ammonium nitrate, including solution, in pack >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)	Import price (UK): 'Ammonium nitrate, including solution, in pack >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)
Triple superphosphate, as P2O5	Import price (DK): 'Superphosphates, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 07/10/2014)	Import price (DE): 'Superphosphates, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 07/10/2014)	Import price (SE): 'Superphosphates, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)	Import price (UK): 'Superphosphates, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)
Potassium chloride, as K2O	Import price (DK): 'Potassium chloride, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 07/10/2014)	Import price (DE): 'Potassium chloride, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 07/10/2014)	Import price (SE): 'Potassium chloride, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)	Import price (UK): 'Potassium chloride, in packs >10 kg'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)

Electricity	DK industry use price 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency	DE industry use price 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency	SE electricity prices for industry 2012: IEA (2013, III.57), Electricity Information 2013. International Energy Agency	UK electricity prices for industry 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency
Heat	DK average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/Germany-78.aspx (Accessed 08/01/2015)	DE average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/Germany-78.aspx (Accessed 08/01/2015)	SE average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/Germany-78.aspx (Accessed 08/01/2015)	Andrews et al. (2012, Table 7.7) Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion
Coal	Assumed the same like Sweden. Import price (SE): 'Coal except anthracite or bituminous, not agglomerate'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/01/2015)	Import price (DE): 'Coal except anthracite or bituminous, not agglomerate'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/01/2015)	Import price (SE): 'Coal except anthracite or bituminous, not agglomerate'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)	Import price (UK): 'Coal except anthracite or bituminous, not agglomerate'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)
Fuel oil	Import price (DK): 'Oils petroleum, bituminous, distillates, except crude'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/01/2015)	Import price (DE): 'Oils petroleum, bituminous, distillates, except crude'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/01/2015)	Import price (SE): 'Oils petroleum, bituminous, distillates, except crude'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03-2015)	Import price (UK): 'Oils petroleum, bituminous, distillates, except crude'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03-2015)

C.2 Plant cultivation system

Plant cultivation system						
Prices	**Unit**	**DK**	**DE**	**SE**	**UK**	**EU**
Barley	EUR2012/kg crop	0.214	0.202	0.187	0.209	
Wheat	EUR2012/kg crop	0.207	0.221	0.217	0.242	0.226
Oat	EUR2012/kg crop	0.200	0.189	0.166	0.237	
Rapeseed	EUR2012/kg crop					0.478
Crop residue	EUR2012/kg straw	0.0720	0.155	0.0720	0.0820	
Electricity	EUR2012 kWh electricity^{-1}	0.0823	0.117	0.0704	0.106	0.143
Heat	EUR2012 MJ heat^{-1}	0.0278	0.0203	0.0206	0.00495	0.0175

Plant cultivation system					
Data sources	**DK**	**DE**	**SE**	**UK**	**EU**
Barley	Production price (DK): 'Barley'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (DE): 'Barley'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (SE): 'Barley'. FAOSTAT (2015), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 21/01/2015)	Production price (UK): 'Barley'. FAOSTAT (2015), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 21/01/2015)	
Wheat	Production price (DK): 'Wheat'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (DE): 'Wheat'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (SE): 'Wheat'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (UK): 'Wheat'. FAOSTAT (2015), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 21/01/2015)	Production price (EU): 'Wheat'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 08/01/2015)
Oat	Production price (DK): 'Oats'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (DE): 'Oats'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (SE): 'Oats'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 12/22/2014)	Production price (UK): 'Oats'. FAOSTAT (2015), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 21/01/2015)	
Rapeseed					Production price (EU): 'Rapeseed'. FAOSTAT (2014), FAOSTAT producer prices. http://faostat.fao.org/ (Accessed 08/01/2015)
Crop residue	Kühner (2013, page 23-26)	Kühner (2013, page 23-26)	Assumed to be the same as in Denmark	Kühner (2013, page 23-26)	
Electricity	DK electricity prices for industry 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency	DE electricity prices for industry 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency	SE electricity prices for industry 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency	UK electricity prices for industry 2012: IEA (2013, p III.57), Electricity Information 2013. International Energy Agency	EU-27 Electricity prices for industrial consumers (bi-annual data) (2012): Eurostat (Accessed 08/01/2015)
Heat	DK average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/Germany-78.aspx (Accessed 08/01/2015)	DE average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/Germany-78.aspx (Accessed 08/01/2015)	SE average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/Germany-78.aspx (Accessed 08/01/2015)	Andrews et al. (2012, Table 7.7) Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion	Calculated EU average district heating price in 2011: Euroheat&Power, http://www.euroheat.org/ (Accessed 08/01/2015)

C.3 Food industry system

Food industry system									
Prices	**Unit**	**DK**	**DE**	**SE**	**UK**	**MY/ID**	**BR**	**FR**	**EU**
Crude palm oil	EUR2012/kg					0.687			
Crude palm kernel oil	EUR2012/kg					0.808			
Crude soybean oil	EUR2012/kg						0.394		
Crude rapeseed oil	EUR2012/kg								0.999
Crude sunflower oil	EUR2012/kg							1.09	
Palm kernel meal	EUR2012/kg					0.0324			
Soybean meal	EUR2012/kg						0.365		
Rapeseed meal	EUR2012/kg								0.256
Sunflower meal	EUR2012/kg							0.190	
NBD palm oil	EUR2012/kg					0.889			
NBD palm kernel oil	EUR2012/kg					0.889			
NBD soybean oil	EUR2012/kg						0.770		
NBD rapeseed oil	EUR2012/kg								1.36
Sugar	EUR2012/kg	0.589	0.662	0.591	0.681				
Flour	EUR2012/kg	0.468	0.359	0.459	0.313				
Kernel	EUR2012/kg					0.379			
EFB for land application	EUR2012/kg					0.00521			
POME for land application	EUR2012/kg					0.00227			
Free fatty acids (FFA)	EUR2012/kg					0.643	0.643		0.643
Molasses (74% DM)	EUR2012/kg	0.137	0.151	0.132	0.134				
Beet pulp, dried (89.4% DM)	EUR2012/kg	0.189	0.148	0.190	0.197				
Wheat bran	EUR2012/kg	0.161	0.174	0.275	0.203				
Electricity	EUR/kWh					0.0776			
Urea, as N	EUR/kg N					0.753			
Phosphate rock, as P2O5	EUR/kg P2O5					0.243			
Potassium chloride, as K2O	EUR/kg K2O					0.716			
Malt	EUR2012/kg	0.358	0.467	0.429	0.520				
Malt sprouts	EUR2012/kg	0.0535	0.0635	0.251	0.285				
Beer (4.6% alc)	EUR2012/kg	0.807	0.691	0.735	1.21				
Brewer's grain (fresh)	EUR2012/kg	0.0535	0.0635	0.251	0.285				
Bioethanol	EUR2012/kg								0.352
DDGS	EUR2012/kg								0.157
Feed energy	EUR/MJ net energy					0.0194			
Feed protein	EUR/kg					0.383			

Food industry system				
Data sources	**DK**	**DE**	**SE**	**UK**
Sugar	Export price (DK): 'Refined sugar, in solid form, nes, pure sucrose'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Export price (DE): 'Refined sugar, in solid form, nes, pure sucrose'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Export price (SE): 'Refined sugar, in solid form, nes, pure sucrose'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 02/03/2015)	Export price (UK): 'Refined sugar, in solid form, nes, pure sucrose'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 02/02/2015)
Flour	Production price, 2011 (DK): 'Wheat or meslin flour'. UNSD (2015), Industrial Commodity Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 18/01/2015)	Production price, 2011 (DE): 'Wheat or meslin flour'. UNSD (2015), Industrial Commodity Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 18/01/2015)	Production price, 2011 (SE): 'Wheat or meslin flour'. UNSD (2015), Industrial Commodity Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)	Production price, 2011 (UK): 'Wheat or meslin flour'. UNSD (2015), Industrial Commodity Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)
Molasses (74% DM)	Import price (DK): 'Molasses, except cane molasses'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Import price (DE): 'Molasses, except cane molasses'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Import price (SE): 'Molasses, except cane molasses'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 02/03/2015)	Import price (UK): 'Molasses, except cane molasses'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 02/03/2015)
Beet pulp, dried (89.4% DM)	Import price (DK): 'Beet-pulp, bagasse & other waste of sugar manufacture'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Import price (DE): 'Beet-pulp, bagasse & other waste of sugar manufacture'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Import price (SE): 'Beet-pulp, bagasse & other waste of sugar manufacture'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 02/03/2015)	Import price (UK): 'Beet-pulp, bagasse & other waste of sugar manufacture'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 02/03/2015)
Wheat bran	Import price (DK): 'Wheat bran, sharps, other residues'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/10/2014)	Import price (DE): 'Wheat bran, sharps, other residues'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 18/01/2015)	Import price (SE): 'Wheat bran, sharps, other residues'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)	Import price (UK): 'Wheat bran, sharps, other residues'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015)
Malt	Export price (DK): 'Malt, not roasted' and 'Malt, roasted'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division.	Export price (DE): 'Malt, not roasted' and 'Malt, roasted'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division.	Export price (SE): 'Malt, not roasted' and 'Malt, roasted'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division.	Export price (UK): 'Malt, not roasted' and 'Malt, roasted'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division.

	http://data.un.org/Browse.aspx?d=ComTrade (Accessed 19/01/2015).	http://data.un.org/Browse.aspx?d=ComTrade (Accessed 19/01/2015).	http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).	http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).
Malt sprouts	Export price (DK): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 19/01/2015).	Export price (DE): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 19/01/2015).	Export price (SE): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).	Export price (UK): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).
Beer (4.6% alc)	Export price (DK): 'Beer made from malt'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/07/2014).	Export price (DE): 'Beer made from malt'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 19/01/2015).	Export price (SE): 'Beer made from malt'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).	Export price (UK): 'Beer made from malt'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).
Brewer's grain (fresh)	Export price (DK): 'Brewing or distilling dregs and waste'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 08/07/2014).	Export price (DE): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 19/01/2015).	Export price (SE): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).	Export price (UK): 'Brewing or distilling dregs and waste'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 03/03/2015).
Feed energy	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.
Feed protein	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.

Food industry system				
Data sources	**MY/ID**	**BR**	**FR**	**EU**
Crude palm oil	MPOB (2013), MALAYSIAN OIL PALM STATISTICS 2012. Malaysian Palm Oil Board. http://econ.mpob.gov.my/upk/monthly/bh_monthly_12.htm (Accessed 15/01/2015)			
Crude palm kernel oil	MPOB (2013), MALAYSIAN OIL PALM STATISTICS 2012. Malaysian Palm Oil Board. http://econ.mpob.gov.my/upk/monthly/bh_monthly_12.htm (Accessed 15/01/2015)			
Crude soybean oil		Production price (Brazil): 'Oil, soya-bean, crude'. UNSD (2014), Industrial Commodity Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade Data for 2010 (Data for 2012 unavailable) (Accessed 08/10/2014)		
Crude rapeseed oil				Export price (EU): 'Canola, rape, colza or mustard oil, crude'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 18/01/2015)
Crude sunflower oil			Export price (France): 'Sunflower-seed or safflower oil, crude'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 16/01/2015)	
Palm kernel meal	Palm kernel expeller, MPOB (2013), MALAYSIAN OIL PALM STATISTICS 2013. Malaysian Palm Oil Board. http://econ.mpob.gov.my/upk/monthly/bh_monthly_12.htm (Accessed 15/01/2015)			
Soybean meal		Export price (Brazil): 'Soya-bean oil-cake and other solid residues'. UNSD (2014), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=Co		

		mTrade Data for 2010 (Data for 2012 available but changed to 2012 to be consistent with the others) (Accessed 08/10/2014)		
Rapeseed meal				Export price (EU): 'Rape or colza seed oil-cake and other solid residues'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 18/01/2015)
Sunflower meal			Export price (France): 'Sunflower seed oil-cake and other solid residues'. UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 16/01/2015)	
NBD palm oil	Price for refining step of 1 kg is assumed same as for crude palm oil. This is added to CPKO			
NBD palm kernel oil	Price for refining step of 1 kg is assumed same as for crude palm oil. This is added to CPKO			
NBD soybean oil		Production price (Brazil): 'Oil, soya-bean, refined'. UNSD (2014), Industrial Commodity Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Data for 2010) (Accessed 08/10/2014)		
Kernel	MPOB (2013), MALAYSIAN OIL PALM STATISTICS 2012. Malaysian Palm Oil Board. http://econ.mpob.gov.my/upk/monthly/bh_monthly_12.htm (Accessed 15/01/2015)			
EFB for land application	Calculated based on fertiliser prices and nutrient content of EFB			
POME for land application	Calculated based on fertiliser prices and nutrient content of POME			
Free fatty acids (FFA)	MPOB (2013), MALAYSIAN OIL PALM STATISTICS 2012. Malaysian Palm Oil Board. http://econ.mpob.gov.my/upk/monthl			

	y/bh_monthly_12.htm (Accessed 09/10/2014)			
Electricity	Electricity, rate for 2011, 'Tariff C1 - Medium Voltage General Commercial Tariff': Tenaga Nasional, http://www.tnb.com.my/business/for-commercial/pricing-tariff.html			
Urea, as N	Import prices (Malaysia): UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 15/01/2015) (0.46 is N in urea)			
Phosphate rock, as P2O5	Import quantity for 2007 (Malaysia): UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade Import value for 2007: FAOSTAT (Both accessed 19/01/2015)			
Potassium chloride, as K2O	Import prices (Malaysia): UNSD (2015), Commodity Trade Statistics Database. United Nations Statistics Division. http://data.un.org/Browse.aspx?d=ComTrade (Accessed 15/01/2015)			
Bioethanol				United States Department of Agriculture (2015). Downloaded from http://www.ams.usda.gov/mnreports/lswethanol.pdf. (Accessed 18/01/2015). Data represent the market in United States the first week of 2012, and are used.
DDGS				United States Department of Agriculture (2015). Downloaded from http://www.ams.usda.gov/mnreports/lswethanol.pdf. (Accessed 18/01/2015). Data represent the market in United States the first week of 2012, and are used.

Feed energy	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.	Calculated based on price of soybean meal in Brazil 2012 export price (UNSD 2015, Commodity Trade Statistics Database) and price of barley, average of Russia, Ukraine and France in 2012 (FAOSTAT 2015). These data are combined with data on the content of protein and net energy in the two feed commodities.
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