National and farm level carbon footprint of milk

Methodology and results for Danish and Swedish milk 2005 at farm gate

Preface

The model described in the current report is referred to as 'the Arla model'. The Arla model is documented in a methodology report (the current report) and an inventory report. The methodology report defines the methodology for inventorying milk production at farm gate. Basically, this means that the methodology report defines all model parameters and links them in formulas. The inventory report identifies and documents the parameter values.

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1 Introduction

Arla Foods wants to estimate and track the development in greenhouse gas (GHG) emission per kg raw milk – both at farm level, national level as well as corporate level which include emissions in several countries. The current report concerns a CF model for raw milk from cradle to farm gate.

The modelling of life cycle emissions for agricultural products is associated with several challenges. The production systems are most often characterised by having several co-products, and the most significant emissions are related to biological processing, such as enteric fermentation and altering of nutrient balances as opposed to LCAs in other sectors where most emissions are related to the combustion of fuels (Schmidt 2010a). The modelling of co-products is one of the major challenges in the modelling of life cycle emissions. The modelling of emissions in agricultural production systems involves a large number of activity and product parameters and the models (IPCC models for GHG-emissions) are often related to significant uncertainties.

A key challenge for Arla is that different methods for calculating the carbon footprint (CF) are often used in the countries where Arla operates. The following relevant modelling approaches have been identified:

- Consequential modelling (CLCA), which is most often used in Denmark.
- Average/allocation or attributional modelling (ALCA), which is typically used in Sweden and the UK.
- In the UK a national CF guideline called PAS 2050 has been developed (PAS2050 2008; Dairy UK et al. 2010). PAS2050 is a sub-set of the attributional modelling with some specific rules for specific activities.
- At industry level, the International Dairy Federation (IDF) has also completed a CF guideline specifically for milk and dairy products (IDF 2010). The IDF guideline is a sub-set of the attributional modelling with some specific rules for specific activities.

Arla Foods 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. The latter requires that the same model is used in all countries. The model developed in the present project, therefore have built-in switches that enables to use the same data, but to get the CF results according to the different modelling approaches. Hence, the model makes it possible for Arla to compare results across markets as well as within markets. The purpose of the present project is to:

1. Calculate a baseline for Denmark and Sweden for 2005 of the average CF for milk according to the four modelling approaches referred to above.
2. Develop a tool to calculate the CF on farm level, which will help to follow the development in CF per kg milk according the same guidelines and approaches as for item 1.

Compared to a ‘normal’ CF model, the current model is generically described with input parameters and formulas. Then the same model can be used for calculating the CF baseline for different countries as well as farm specific CF. The generic model and country baseline results are described in the current report. All input parameters are described in an inventory report (Dalgaard and Schmidt 2012).

The special features and the generic nature of the Arla model require that the framework for the life cycle inventory is defined consistently. Therefore, before the actual CF model is described in **chapter 4** to **9**, the inventory framework is described in **chapter 3**.

2 Description of the milk 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 to be slaughtered. A heifer becomes a milking cow when it born 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, plant cultivation and food industries are illustrated in **Figure 2.1**.

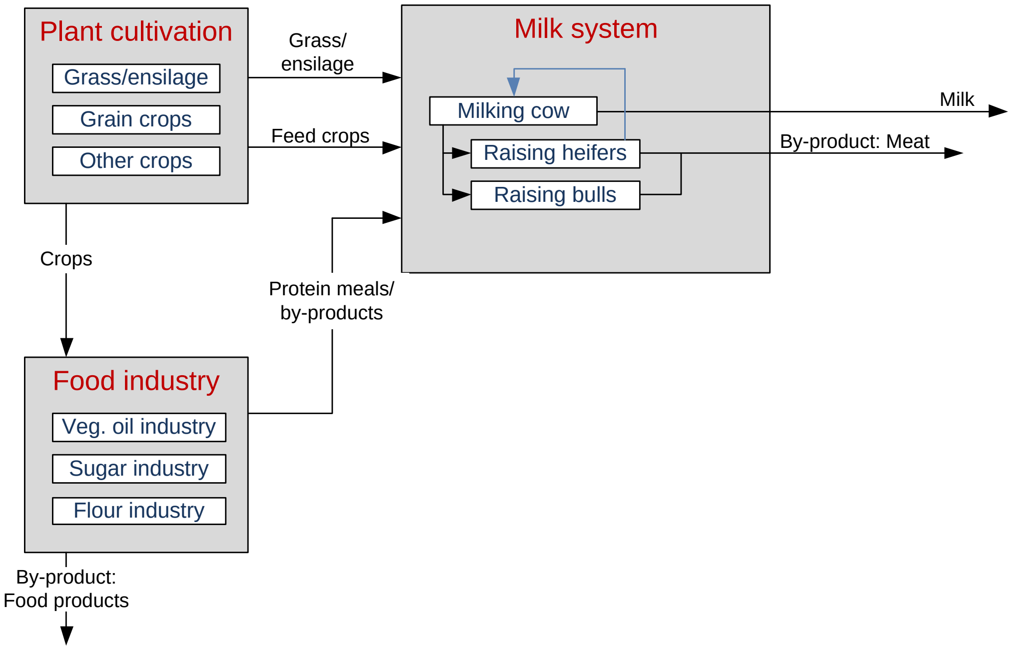

Figure 2.1: Overview of the milk product system. In addition to the shown product stages, there are also several other involved industry sectors, such as transportation, electricity generation, fuel production, fertiliser production etc.

When calculating the CF for milk, the major GHG-emissions from the milk system, i.e. the animals, are related to methane from enteric fermentation and manure management, but also nitrous oxide 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) 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).

Table 2.1 below provides a general characteristic of the Danish and Swedish milk systems. The data are all from the life cycle inventory report of the current study (Dalgaard and Schmidt 2012).

Table 2.1: Characteristics of the Danish and Swedish milk systems (Dalgaard and Schmidt 2012).

Characteristic	Unit	Denmark	Sweden
Number of dairy cows	annual average	563,500	393,268
Milk yield	kg ECM per cow per year	8,440	8,271
Share of net energy from roughage	%	53	60
Age at first birth	months	28.6	28.1
Dairy cow age at slaughter	Years	5.4	5.0
Time outdoor	% of year	15	21
Weight of bull at slaughter	kg live weight	420	565
N excreted from dairy cow	kg N per year	125	124
N excreted handled as liquid/slurry	% of N excreted	74.9	56.0
N excreted handled as solid	% of N excreted	4.9	23.2

3 Life cycle inventory theory; framework, terms and definitions

This chapter describes and defines the terms used in the current report. **Chapter 3.1** puts the main terms in a context, i.e. in a general framework for life cycle inventory, and **chapter 3.2** provides an alphabetical sorted list of definitions of terms used throughout the report.

This chapter on general life cycle inventory theory is needed because the scope of the current project is wider than just following the ISO 14040/44 standards on LCA and ISO 14067 on carbon footprint; life cycle results are calculated based on a common database, but different modelling assumptions are consistently applied throughout the database. Therefore, the inventory needs to be split into two parts:

- accounting part; where data are stored as they are, i.e. no assumptions on allocation or geographical and technological delimitation are applied
- modelling part; where different modelling assumptions regarding allocation and geographical and technological delimitation are applied

The ISO standards (or any guideline or methodology report on LCA) do not provide a framework that enables for this. Therefore, this theoretical chapter is needed in order to establish the required life cycle inventory framework.

3.1 Naming conventions of activities and products in life cycle inventory (LCI)

Product system, system boundary and flows

A life cycle inventory consists of a number of interconnected activities (also sometimes known as LCA processes), see **Figure 3.1**. The activities are connected via products. The term ‘Products’ here covers determining and dependant co-products as well as products with and without a market value and wastes. An activity may have exchanges with the environment, i.e. emissions or other exchanges (radiation, noise, odour etc.) to the environment or resource inputs or other exchanges (occupation and transformation of land) from the environment. Activities are human, and they take place within the technosphere. Product transactions also always take place between activities in the technosphere. When calculating the inventory result, it is the sum of all exchanges with the environment that are calculated. The inventory result is used for calculating potential environmental impacts.

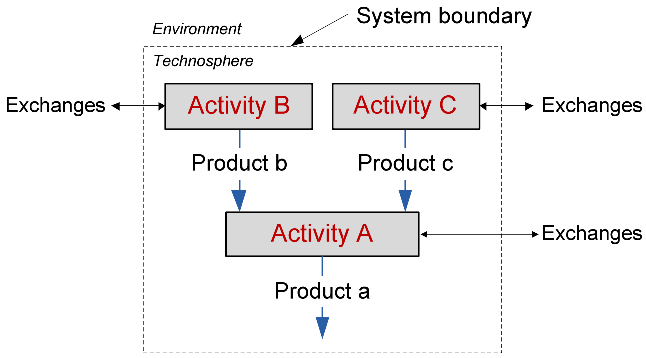

Figure 3.1: Product system with system boundary between environment and technosphere. Within the technosphere are activities which are linked via product and waste flows. Exchanges with the environment are flows that cross the system boundary. These are the ones recorded for the calculation of environmental impact indicators.

Different types of flows within the technosphere

Flows within the technosphere can be differentiated based on the characteristics relevant in an LCI context. Distinction is made between:

- reference products
- by-products
- material for treatment

Reference products are characterised by determining the production volume of an activity, i.e. a change in demand for a reference product affects the production volume of the activity. An activity can have one or more reference products, but most often, there will only be one reference product.

By-products are products which can directly displace a reference product supplied by another activity. The difference between reference products and by-products is that a change in demand for by-products does not change the production volume of the supplying activity.

Materials for treatment are outputs which cannot directly displace a reference product supplied by another activity before it has been treated in a treatment activity. Treatment activities may turn the material into a by-product, material for treatment and/or emissions. Similar to by-products, a change in demand for materials for treatment does not change the production volume of the supplying activity.

Different types of activities

Distinction is made between two types of activities:

- Activities
- Treatment activities

A treatment activity is characterised by receiving 'material for treatment'. Treatment activities include waste treatment, recycling, reuse, and other processing of material outputs of activities into products that can displace reference products. **Figure 3.2** illustrates an activity A that supplies a reference product A, a material for treatment, and a by-product B. The by-product B from activity A can directly displace the reference product B from activity B. The material for treatment from activity A needs treatment in the treatment activity before the material can displace another product, here reference product B from activity B.

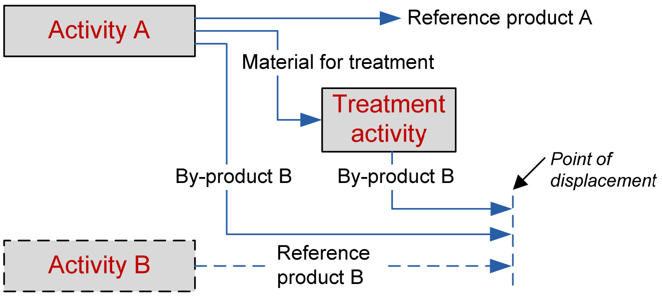

Figure 3.2: Naming conventions of different types of products and activities. The dotted line represents the displacement of product and activity B. The figure is based on Weidema et al. (2009, p 19).

Difference between substitution and allocation

Multiple-output activities are characterised by having more than one product output. When demanding only one of the co-products, we have a so-called allocation problem. In modelling terms, this problem can be solved either by substitution or by allocation. In substitution, it is determined which one(s) of the co-products that are determining, i.e. a change in demand for this/these products affects the production volume of the activity. The remaining co-products are dependant, i.e. the output of these products is not affected by a change in demand. Hence, a change in demand for determining products will also cause a change the output of the dependant co-products. The general assumption in LCA is that demand determines supply. Thus, a change in output of dependant co-products will cause a reduction in the alternative supply of these products (this is regulated through the markets for substitutable products). The modelling and system boundary for a change in demand for the determining product A, is illustrated in **Figure 3.3**. The technicalities and theory behind substitution are described in detail in Weidema et al. (2009).

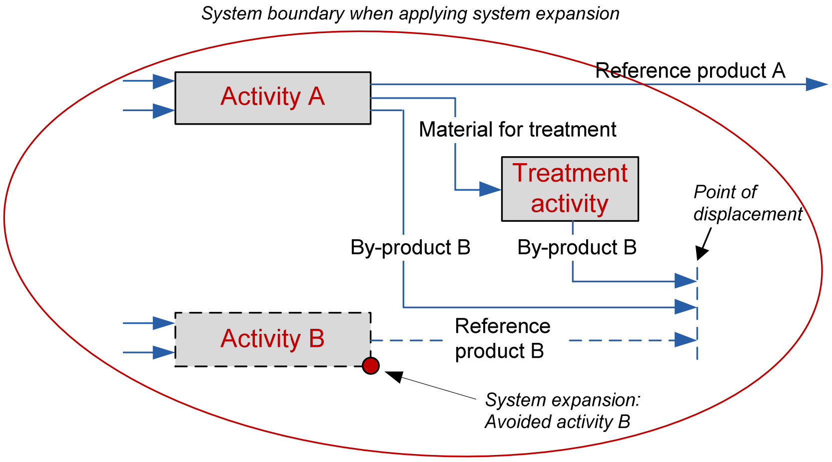

Figure 3.3: Multiple-output activities: Modelling of substitution.

When the allocation problem is solved by allocation, each of the product outputs are converted to an allocation unit, e.g. EUR if economic allocation is applied, or MJ if energy allocation is applied. Then the relative outputs of the co-products measured in allocation unit determine the portion of the multiple-output system that is ascribed to each co-product. The interactions with other product systems supplying substitutable products to the same market (the avoided activities in substitution) are not considered in allocation.

As illustrated in **Figure 3.4** and **Figure 3.5**, allocation can be carried out in two different ways/at two different points. In the following, allocation as in **Figure 3.4** and **Figure 3.5** are referred to as type I and type II allocation respectively.

Type I allocation represents allocation at the point of substitution (after treatment activities), whereas type II represents allocation immediately after the multiple output activity before treatment activities and not at point of displacement.

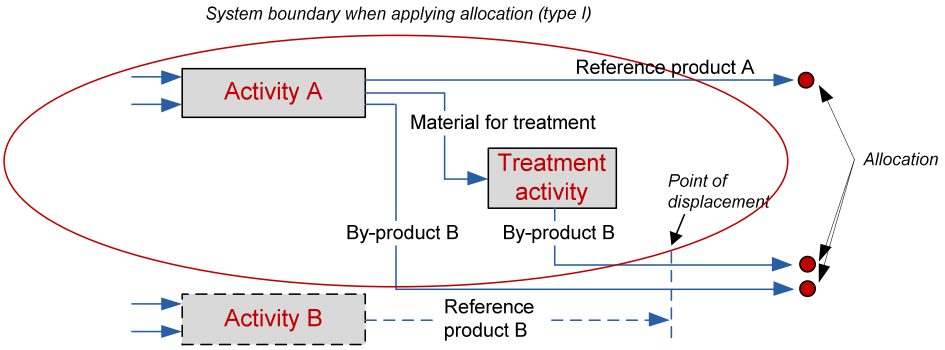

Figure 3.4: Multiple-output activities: Modelling of allocation (type I): allocation is done at point of displacement after treatment activity.

There are instances where the included standards (PAS2050 and IDF) prescribe that the allocation model as illustrated in **Figure 3.4** shall not followed, i.e. where allocation is carried at other points than at the point of displacement. To enable for this, the principle of system boundary and allocation may be as illustrated in **Figure 3.5**.

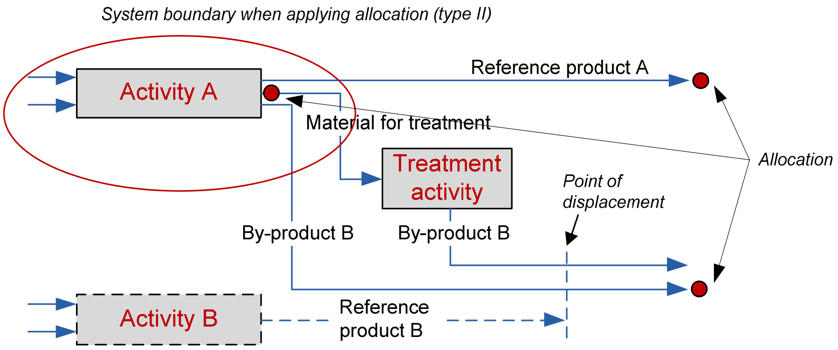

Figure 3.5: Multiple-output activities: Modelling of allocation (type II): allocation is done before treatment activity and not at point of displacement.

3.2 Definition of terms and abbreviations

a.s.	Active substance (in pesticides).
Activity	Part of technosphere. The doing or making something. Usually, activity refers to productive activities that aim at selling the resulting products to other activities. In LCA literature, activities are sometimes referred to as processes.
AN	Ammonium nitrate (fertiliser).
AS	Ammonium sulphate (fertiliser).
Attributional modelling	“*System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.*” (Sonnemann and Vigon 2011, p 132). In the current study attributional modelling is modelled by assuming that the products are produced using existing production capacity (current or historical market average), and multiple-output activities are dealt with by applying allocation factors based on economic value.
By-product	Non-determining product that directly (i.e. without further processing) is used in place of other products.

CAN	Calcium ammonium nitrate(fertiliser).
Carcass weight (CW)	the weight of the slaughtered animal's cold body after being skinned, bled and eviscerated, and after removal of the external genitalia, the limbs, the head, the tail, the kidneys and kidney fats, and the udder (Eurostat 2012).
Consequential modelling	"*System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.*" (Sonnemann and Vigon (2011, p 133). Hence, in consequential modelling it is generally a change in demand of the product under study that is modelled. A cause-effect relationship between a change in demand and the related changes in supply is intended to be established. This implies that the product is produced by new capacity (if the market trend is increasing). Also it is taken into account that the affected production capacity must be the actual affected, i.e. it is not constrained. Multiple-output activities are dealt with using substitution. The modelling principles are comprehensively described in Weidema et al. (2009) and Weidema (2003).
CPO	Crude palm oil.
CPKO	Crude palm kernel oil.
CRSO	Crude rapeseed oil.
CSBO	Crude soybean oil.
CSFO	Crude sunflower oil
DLUC	Direct land use changes; transformation of land, e.g. transformation of natural forest to arable land, which takes place within the activity that occupies land (Schmidt et al. 2012).
DM	Dry matter.
ECM	Energy corrected milk.
EFB	Empty fruit bunches. This is what is left from oil palm fresh fruit bunches (FFB) when the fruits have been ripped off.
EU	European Union.
Exchanges with the environment	Exchanges between the technosphere and the environment; Emissions, resource inputs, land use exchanges (occupation and transformation), and other such as radiation, noise, odour, vibrations, aesthetical effects on landscape etc.
FFA	Free fatty acids. This is a by-product from refinery of crude vegetable oils.
FFB	Fresh fruit bunches. This is what is harvested from oil palm plantations.
GWP	Global warming potential. Defined in IPCC (2007).
GWP100	Global warming potential calculated using a time horizon of 100 years. Defined in IPCC (2007).
ILUC	Indirect land use changes; the upstream consequences of the occupation of land, e.g. 1 ha during 1 year. These consequences can be e.g. transformation of natural forest to arable land and intensification of land already in use (Schmidt et al. 2012).

Live weight (LW)	Live weight of animals intended for slaughter is the weight taken immediately before slaughter (FAOSTAT 2012).
Material for treatment	Output flow of a human activity that remains in the technosphere and cannot directly (i.e. without further processing in a treatment activity) displace a reference product.
NBD oil	Neutralised, bleached and deodorised oil – or just refined oil.
n.e.c.	Not elsewhere classified.
p	Piece or amount.
PKM	Palm kernel meal.
PKO	Palm kernel oil.
PO	Palm oil
POME	Palm oil mill effluent
Product	Output flow from a human activity with a positive either market or non-market value. Further distinction of the products can be made in terms of determining products and by-products.
Reference product	Product for which the production volume changes in response to changes in demand.
RSM	Rapeseed meal.
RSO	Rapeseed oil.
SBM	Soybean meal.
SBO	Soybean oil.
SBM	Soybean meal.
SFM	Sunflower meal.
SFO	Sunflower oil.
SFU	Scandinavian fodder unit.
TSP	Triple super phosphate.
WB	Wheat bran.

3.3 Country codes

BR	Brazil
DK	Denmark.
FR	France.
MY	Malaysia.
GLO	Global.
RU	Russia.
SE	Sweden.
UA	Ukraine.

4 Goal and scope definition

4.1 ISO 14040/44 on LCA

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

It should be noticed that the LCA is not critical reviewed which is required in ISO 14044.

4.2 Functional unit and purpose of the study

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).

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

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

Purpose of the study

Arla Foods wants to estimate and track the development in greenhouse gas (GHG) emission per kg raw milk – both at farm level, national level as well as corporate level which include emissions in several countries. The current report concerns a CF model for raw milk from cradle to farm gate. At a later stage, the current study may provide as an input to an LCA or CF of milk derived products from dairy.

In addition to the above mentioned purpose of the study, another purpose is that the model is applicable in different contexts where different methodologies for modelling the CF of milk are applied. This includes the following methods/standards:

- **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. 2011).
- **Average/allocation:** market average mixes of suppliers and allocation is carried out by use of allocation (economic). The applied modelling assumption is often referred to as attributional. 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. 2011).
- **PAS2050** (PAS2050 2008; Dairy UK et al. 2010)
- **IDF guideline** (IDF 2010)

4.3 Modelling in life cycle inventory and parameter switches

The Arla model stores the life cycle inventory data in a way that enables for applying different modelling assumptions. By use of switches, it is possible to calculate the life cycle results based on the included sets of modelling assumptions. This includes:

1. ISO 14040/44 on life cycle assessment
2. Average allocation attributional modelling
3. PAS2050 (PAS2050 2008)
4. IDF guideline (IDF 2010)

Consequential and attributional modelling

Generally there exist two different approaches to modelling in life cycle inventory:

- consequential modelling
- attributional modelling

According to Sonnemann and Vigon (2011, p 132), attributional modelling is defined as: "*System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.*" In the current study attributional modelling is modelled by assuming that the products are produced using existing production capacity (current or historical market average), and multiple-output activities are dealt with by applying allocation factors based on economic value.

According to Sonnemann and Vigon (2011, p 133), consequential modelling is defined as: "*System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.*" Hence, in consequential modelling it is generally a change in demand of the product under study that is modelled. A cause-effect relationship between a change in demand and the related changes in supply is intended to be established. This implies that the product is produced by new capacity (if the market trend is increasing). Also it is taken into account that the affected production capacity must be the actual affected, i.e. it is not constrained. Multiple-output activities are dealt with using substitution. The modelling principles are comprehensively described in Weidema et al. (2009) and Weidema (2003).

Included modelling approaches and standards

The modelling approaches/standards are included in the model are listed and described in **Table 4.1**.

Table 4.1: 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 actual modelling of each activity in each switch mode is described in the inventory report (Dalgaard and Schmidt 2012). The methodology used for modelling using switches is described in **chapter 5**.

4.4 System boundaries

The system boundaries represent a cradle-to-gate perspective for milk production, at farm-gate. The inventoried product stages are illustrated in **Figure 4.1**.

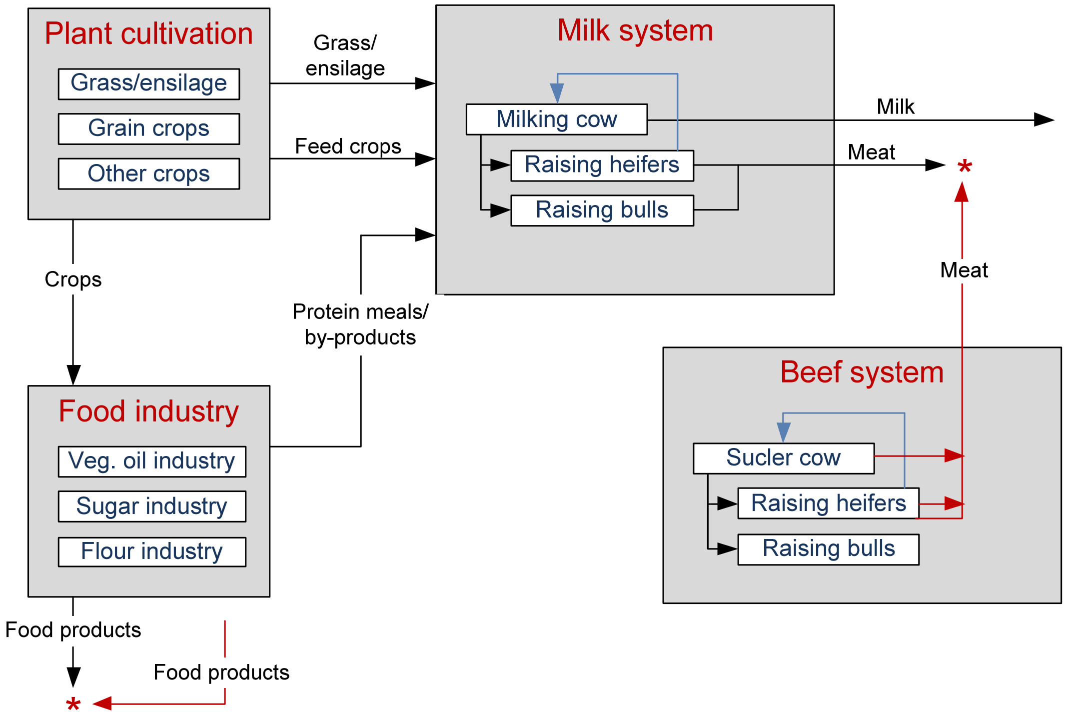

Figure 4.1: Overview of the milk product system. Stars (*) refer to the point of displacement where by-products can substitute alternative production. In addition to the shown product stages, there are also several other involved industry sectors, such as transportation, electricity generation, fuel production, fertiliser production etc.

Temporal aspects of system boundaries

The Arla model calculates baselines for the year 2005.

This temporal system boundary is followed for the milk system, beef system and crop cultivation system, i.e. year specific data are used. For other life cycle stages, representative available data have been used.

4.5 Categories of activities and products and level of detail of data

When carrying out an LCA of milk at farm gate, detailed inventory is essential for some activities whereas more generic data are sufficient for other activities. Detailed inventory is obviously needed for the milk system as well as some upstream activities (feed products) as well as some downstream activities (intermediate treatment of dependant co-products and displaced products).

Detailed inventory has two purposes:

1) to calculate accurate results
2) to enable for the modelling of improvement options and to trace differences between producers

A rough overview of the level of detail in the inventory of different activities is presented in **Table 4.2**, where it is indicated whether specific data have been inventoried or if generic data directly obtained from LCI databases have been used.

activities Products	Milk system	Beef system	Crop cultivation	Food industry	Other industries
Inputs per unit of output					
Agricultural products (crops)	Specific	Specific		Specific	
Feed products	Specific	Specific	Specific		
Fertilisers	Specific	Specific	Specific		
Fuels, electricity, chemicals	Specific	Specific	Specific	Specific	Generic
Other products	Generic	Generic	Generic	Generic	Generic
Emissions per unit of output					
Emissions	Specific	Specific	Specific	Specific	Generic

Table 4.2: Overview of the level of detail (specific/detailed versus generic) of the inventory of the transactions of different categories of products in different categories of activities.

The agricultural activities include the bovine system (milk and meat), cultivation of grass, ensilage, grain crops and other crops, breading of other animals (pigs, poultry etc.), and manure treatment. The feed industry covers the industries that supply feed (almost all feed is co-products from the food industry; protein meals, molasses, whey, etc.), the fertiliser industry includes the production of N, P and K fertilisers used in agriculture. Other industries cover all activities not included in the first three categories. Obviously, the milk system will be the activity within agriculture that is modelled at the highest level of detail.

As it appears from **Table 4.2**, most of the product transactions as well as all emissions in the agricultural activities are inventoried in detail. The only exception is the use of capital goods, services and minor products where generic data are used. Transactions in the feed industry are inventories in detail for feedstocks (input of agricultural products) and energy (and the directly related emissions). The remaining inputs are modelled using generic data. The fertiliser industry is generally inventoried using generic data. However, the emissions of N_2O in the production of ammonium nitrate are validated since these emissions generally are important in agricultural LCAs. All other industries are modelled using only generic data.

4.6 Integrated agriculture balance

The most widely used way to model agricultural activities (crops, animals etc.) is to collect data and model the inputs and outputs of the activity relative to a normalised reference unit. For crops, this inventory reference is often one hectare or one kg crop, and for animal systems it is often one animal year or one kg animal product. So if one kg animal product is inventoried, the production volume of the feed cultivation is determined by the feed use per kg animal product.

Another approach is if the total production volumes of the animal activity and the upstream feed cultivation activity are known. Then it is the feed use per kg animal product which is determined by the production volume of the animal and feed cultivation systems. The advantage of this not-normalised approach is that it enables for additional data consistency checks. If these checks do not show inconsistencies or out of range values, the data quality can often be regarded as being better.

A cattle farm is a good example where the second approach above can be applied to some activities. This is because the production volumes of animal products as well as farm-home-grown feedstuff from feed cultivation are known and because a closed link between the two activities can be established. Not all feedstuff are produced within the cattle farm, and not all cultivated crops are used within the farm. However, this can be accounted for by registering the import of feedstuff to the farm and by registering the crops cultivated with the only purpose to feed the cattle on the farm, e.g. roughage.

A further advantage of the above mentioned data collection and modelling approach for cattle farms is that the yields of roughage are generally not known, and hence it is difficult to establish an inventory for that activity (e.g. it is difficult to inventory the fertiliser use per kg crop if the crop yields are not known). But the use of roughage by cattle can be determined based on the calculated total feed intake (see **section 6.3**) minus the imported feedstuffs (which are generally known). Further, the cultivated areas with roughage are known. Hence, the yields of roughage cultivation can be calculated.

Another advantage of the approach is that the inventory of manure output from the cattle can be balanced with the organic fertiliser input to the crop fields. And also the removed straw from crop cultivation can be balanced with straw for deep litter/bedding/exported from the farm. The straw used internally on the farm can again be balanced with the crop residue input to crop cultivation which is used for field emissions.

Below in **Figure 4.2** an overview of the applied integration between animal activities and crop cultivation activities is presented. Note that only the one-to-one relationships are shown, i.e. where the total supply of a product from one activity is fully used by another activity. Also note that the integration for individual farms is stronger than for the national farm systems. The reduced integration for the national systems is due to the fact that because of lack of data the cultivation of grain crops and other crops are not divided into crops grown on cattle farms and on other farms. For the individual farms this information is available (they know their own cultivation of grain crops and other crops).

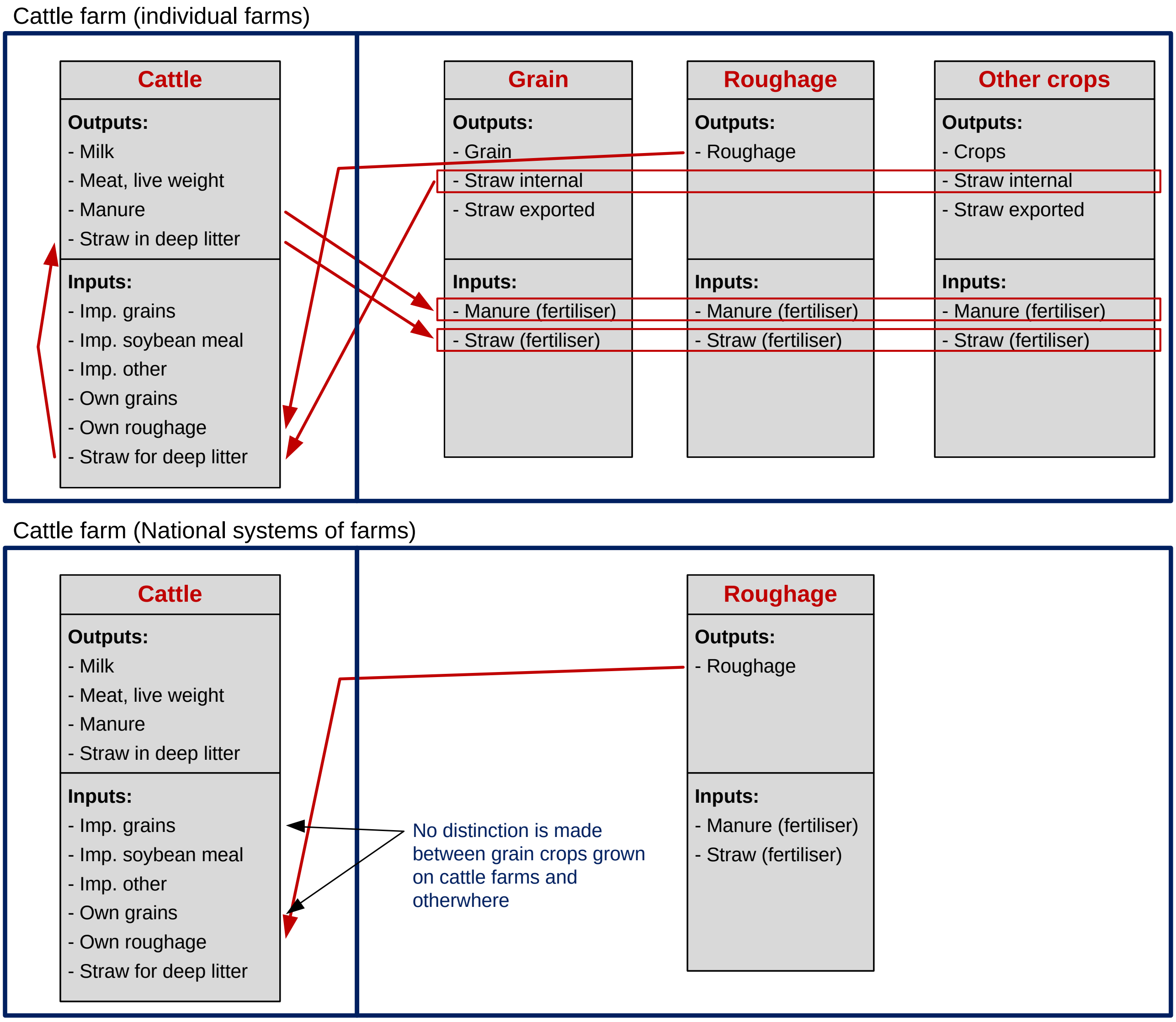

Figure 4.2: Overview of the applied integration between animal activities and crop cultivation activities within a cattle farm (individual farm or sum of national farms). The red arrows represent one-to-one relationships, i.e. where the total supply of a product from one activity is fully used by another activity.

4.7 Cut-off criteria

The life cycle inventory generally operates with three datasets that can be combined so that four different levels of coverage can be applied:

1. Everything is included (cut-off criteria 0%)
2. Everything is included excluding **indirect land use changes (ILUC)**
3. Everything is included excluding **ILUC** and **services**
4. Everything is included excluding **ILUC**, **services**, and **capital goods**

In order to make cut-off criteria at 0% workable in a detailed LCA, the inventoried inputs to activities have in some cases been non-complete and subsequently adjusted to represent the total. This has been relevant in the following cases:

- **the number of inventoried different cattle feed:** For Denmark and Sweden >95% of the feed energy use have been covered by feedstuff for which inventories are included. The remaining feedstuff have been reclassified to similar feedstuff for which inventories are included. This is further described in **chapter 7.2**.
- **the number of crop producers (countries) for barley:** The barley market mixes (Danish market, Swedish market and global markets) are represented by inventories of barley from Denmark, Sweden, European average, Ukraine and Russia because these countries are relevant significant suppliers to the considered markets in the switch modes for ISO14040/44 (consequential) as well as for the average modelling modes. This is further described in **chapter 6.3**.

4.8 Parameter modelling and relation to background data: ecoinvent and ILUC

The Arla model uses specifically collected data for the main products of agricultural activities. But for other activities a large part of the data are based on database data from the ecoinvent database and from other LCI projects. In the following it is described how these background data are compatible with the applied switches in the Arla model.

Ecoinvent

The ecoinvent database v2 is not prepared for the application of different modelling assumptions. Therefore, when direct links to the ecoinvent database are used, the switches have no effect. However, these cases will only have minimal effect on the results, since all significant activities sensitive to modelling assumptions have been modelled specifically.

The ecoinvent database in the LCA software SimaPro 7.3 enables for switching capital goods on and off. This function as been used in order to identify life cycle emissions related to capital goods.

Electricity

Data on electricity are based on Schmidt et al. (2011). This is an electricity life cycle inventory project[1] which allows for different switch settings:

1. Consequential future (based on data for 2008-2020)
2. Consequential historical (based on data for 2000-2008)
3. Consequential coal (100% coal)
4. Attributional (applied average data for year2008)

In the modelling of electricity, the consequential (future) and the attributional scenario are used.

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[1] http://www.lca-net.com/projects/electricity_in_lca/

Indirect land use changes (ILUC)

The method for incorporating ILUC in the results is based on Schmidt et al. (2012), which is an indirect land use change project[2]. This model is implemented and linked to the ecoinvent database, and the model is prepared for applying both attributional and consequential modelling assumptions.

4.9 Life cycle impact assessment (LCIA) method

The study is a carbon footprint study. Hence, the only included impact category is GHG-emissions. The IPCC 100 year global warming potential (GWP) is used for this purpose (IPCC 2007).

Biogenic CO_2

Generally, inputs and outputs of biogenic CO_2 are considered as having no effect on global warming. However, in some cases biogenic CO_2 is relevant and included. This applies to indirect land use changes (ILUC).

Differentiation over time for emissions

Generally, all emissions are modelled as if they are emitted at the same time. This means that it is assumed that emissions today have the same importance as emissions taking place in 100 years. However, for biogenic emissions related to indirect land use changes (ILUC), the time effects are included. The inclusion if the time effects for the different parameter switches are summarised below:

1. Consequential modelling: the GWP 100 method is combined with the Bern carbon cycle equation (IPCC 2007, table 2.14). This is further described in Schmidt et al (2012).
2. Attributional modelling: the GWP 100 method is combined with the Bern carbon cycle equation (IPCC 2007, table 2.14). This is further described in Schmidt et al (2012).
3. PAS2050: Amortisation period at 20 years is applied (PAS 2050, 2008)
4. IDF: Amortisation period at 20 years is applied (IDF 2010)

Other situations where time differentiation is relevant are for storage of carbon in long lasting products and for combustion of biomass that has a long regrowth period, e.g. wood. These situations does not appear or are only associated with limited product volumes in the Arla project product system. Hence, time differentiation is not considered for the above mentioned situations.

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[2] http://www.lca-net.com/projects/iluc_model/

5 Methodology for switching between consequential/attributional

The model enables the calculation of LCA results using all the modelling approaches/standards described in **Table 4.1**. This is done by use of parameters which switch between modelling assumptions and completeness of data. The differentiation between the modelling approaches by use of parameters is described in the following.

5.1 Definition of switches

In order to enable switching between the standards/guidelines in **Table 4.1**, a parameter (M) is defined where M $\in$ [1;2;3;4]. The meaning of the allowed parameter values of M is described in **Table 5.1**. The value of M determines the values of four parameters m_i used in the LCI calculations.

Table 5.1: Modelling approach switch (M) and the meaning of its values. The calculated parameters m_i are used in the actual calculations. When a calculated parameter m_i is 0, then it is turned off, and when it is 1, then it is turned on.

Value M	Applied standard/guideline	Calculated parameter m_i used in LCI calculations
1	ISO14040/44: consequential	if(M=1, m_1 = 1 AND m_2=m_3=m_4=0), else
2	Average/allocation: attributional	if(M=2, m_2 = 1 AND m_1=m_3=m_4=0), else
3	PAS2050	if(M=3, m_3 = 1 AND m_1=m_2=m_4=0), else
4	IDF	if(M=4, m_4 = 1 AND m_1=m_2=m_3=0)

5.2 Switching between affected suppliers and market averages

It is relevant to distinguish between suppliers when products are purchased on a market. If a product is purchased directly from a specific flexible supplier, then this is the affected one, and there is no difference between consequential and attributional modelling. When products are purchased on a market, a so-called market activity is inserted between the suppliers and the activity having the purchased product as input. In this market activity, the parameters controlling which suppliers are included are implemented.

It appears from **Table 4.1** that the applied modelling approaches/standards apply different rules regarding included suppliers. Generally, the included modelling approaches/standards only operate with two different sets of included suppliers for products purchased on the market:

1. Actual affected suppliers, e.g. a market mix without constrained suppliers (M=1)
2. Market average mix including constrained suppliers (M$\in$[2;3;4])

Figure 5.1 illustrates that the above mentioned two different market mixes can be applied depending on which modelling approach is used. The switch between attributional and consequential changes the applied market mix for product A. In attributional modelling, the market shares of each supply of product (msa) correspond to the average market mix of product A. In consequential modelling, the market share of each supply of product (msc) represents the expected proportion of suppliers to respond to a change in demand for product A. In cases where supplies of product A are dependant co-products (as of supplier 3 in the figure), the market share is zero (as msc3 in the figure) because these products are constrained by the demand for the determining product of the multiple-output activity (demand for product B in the figure).

For each market activity, the msa and msc market shares must be defined. The suppliers of a certain product (A) are: supplier 1, supplier 2, supplier 3 etc. For each supplier, the market share of product A is specified both for attributional modelling and for consequential modelling. This is illustrated in **Table 5.2**. It should be noted, that data for msc and msa as in **Table 5.2** must be present for all products purchased from the market in the model.

Table 5.2: Market shares of suppliers for a product A. msc specifies the market shares in consequential modelling and msa specifies the market shares in attributional modelling.

Suppliers of product A	Market share, consequential (msc)	Market share, attributional (msa)
Supplier 1	msc1	msa1
Supplier 2	msc2	msa2
Supplier 3	msc3	msa3
etc.	etc.	etc.

The implementation of the parameters for market mix (margin in consequential modelling vs. average in attributional modelling) is shown in **Figure 5.1**. When the switch (M) is M=1, then the msc marked share is applied, and when the switch M is having the value 2, 3 or 4, then the msa market share is applied.

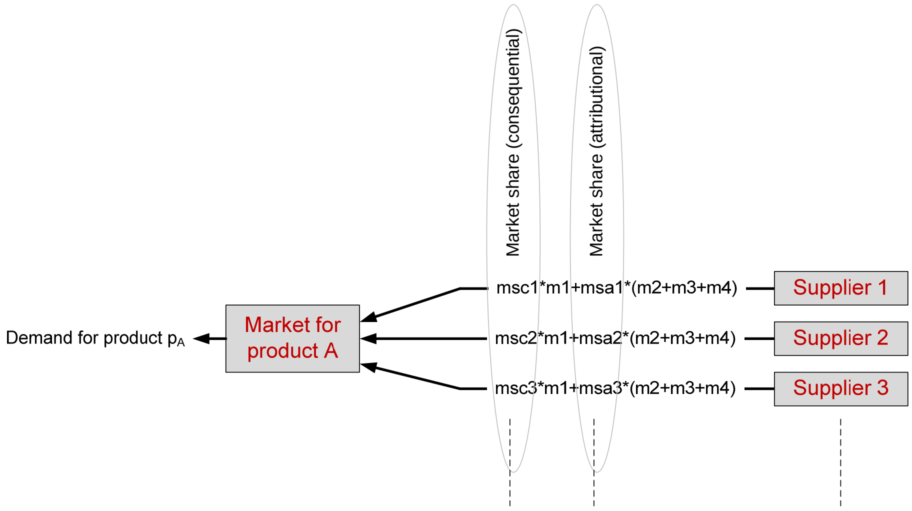


Figure 5.1: Market activities: modelling of average market mix (in attributional modelling) and marginal marked mix (in consequential modelling).

5.3 Switching between substitution and allocation type I and II

According to **Table 4.1**, the standards/guidelines operate with the following types of modelling choices for multiple-output activities:

1. ISO 14040/44 (M=1): Substitution
2. Attributional (M=2): Economical type I allocation
3. PAS2050 (M=3): Mix of substitution and type I and II allocation. In PAS2050 and Dairy UK et al. (2010) it is specified which modelling that shall be applied in different situations. If no guidance is provided, substitution is applied
4. IDF (M=4): Mix of substitution and type I and II allocation. In IDF (2010) it is specified which modelling that shall be applied in different situations. If no guidance is provided, substitution is applied

Hence, the model must enable for switching between substitution and type I and II allocation.

When modelling substitution and allocation, the flows of concern, i.e. the flows which determine the substituted systems and allocation factors are the supply flows of the multiple output activities. **Figure 5.2** provides an overview and notation of the supply-flows of concern when switching between substitution and allocation type I and II. **Figure 5.2** includes two treatment activities. In the life cycle inventory, the number of subsequent downstream treatment activities and materials for treatment will vary from activity to activity.

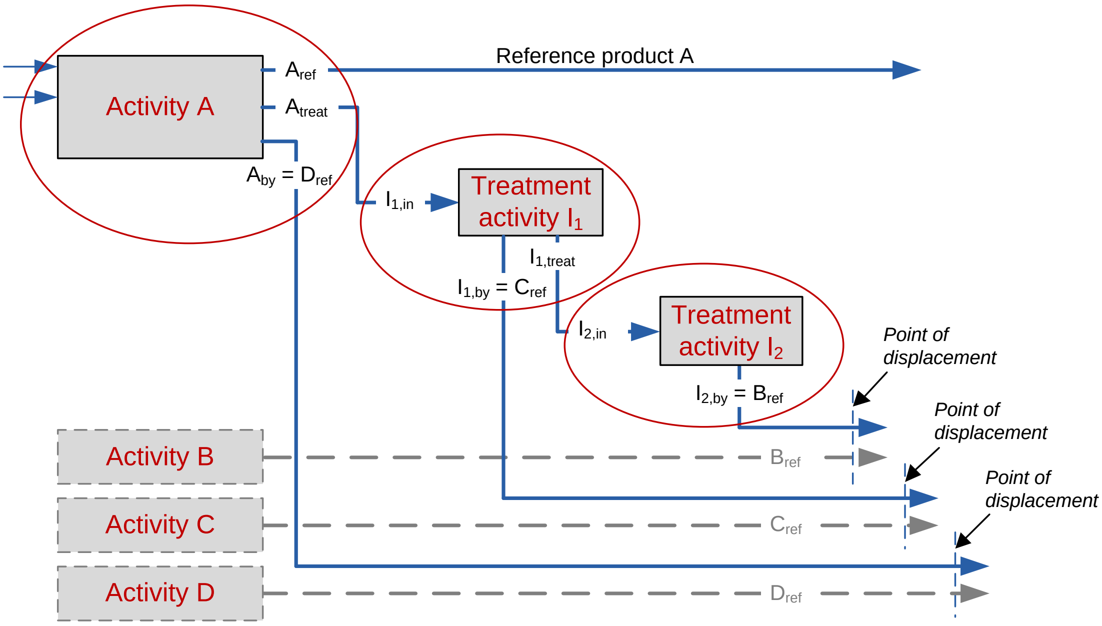


Figure 5.2: Notations of supply-flows used for a generalized description of the modelling of multiple-output activities when using substitution and type I and type II allocation. Flow names A, I_1, I_2, B, C and D refer to the supplying activities, subscript 'ref' refers to reference product, subscript 'by' refers to by-product, subscript 'treat' refers to material for treatment, and subscript 'in' refer to input of material for treatment.

The following name conventions related to **Figure 5.2**: are used in the following

- **Flow names:** A, I_1, I_2, B, C and D refer to the supplying activities
    - subscript 'ref' refers to reference product
    - subscript 'by' refers to by-product
    - subscript 'treat' refers to material for treatment, and
    - subscript 'in' refer to input of material for treatment.
- **Flow quantities (q):** the letter 'q' is put in front of the flow name. Examples of flow quantities are: kg, MJ, ha etc.
- **Flow allocation values (av):** the letter 'av' is put in front of the flow name. Allocation value is a flow property used for allocation. Examples of flow allocation values are: price (EUR/kg), protein content (kg protein/kg) etc.
- **Flow allocation units (au):** the letter 'au' is put in front of the flow name. Allocation unit is the flow quantity converted to another unit which is used for allocation. Examples of flow allocation units are: economic output (EUR), protein output (kg protein) etc.
- **Flow allocation factor (af):** the letter 'af' is put in front of the flow name. Allocation factor is the proportion of the supplying activity which is ascribed to the flow quantity

In **Figure 5.2**, note that the by-products are equivalent (=) to the products they substitute when applying substitution. Hence, if an activity supplies a by-product A_{by}, substitution can be applied by ensuring that activity A substitutes B_{ref}. In this case, activity B is linked to activity A by the reference product of activity B. This is further described in **Table 5.4**.

When inventorying activities the supply of flows is divided into:

- Reference products
- By-products
- Materials for treatment

For ordinary activities (i.e. non-treatment activities, e.g. activity A in **Figure 5.2**) this distinction is relatively straight forward (see Weidema et al 2009, pp 17-22), but for treatment activities (activities I_1 and I_2 in **Figure 5.2**), the reference flow is special. The production volume of treatment activities is characterised by being determined by the incoming material for treatment. Hence, for treatment activities the reference product is defined as the input of material for treatment. Since reference products are on the supply side of activities, this can either be specified as a negative supply of material for treatment or as 'treatment of [the material]'. In the following the latter is used. The reason for this choice is that LCA software currently not supports negative quantities of reference flows. The reference flows of treatment activities I_1 and I_2 in **Figure 5.2** are illustrated as $q_{I1,in}$ and $q_{I2,in}$ respectively.

In **Table 5.3**, the supply-flows of the three activities in **Figure 5.2** are divided into reference products, by-products and materials for treatment. **Table 5.3** represents pure accounting of the activities, i.e. no modelling assumptions on substitution or allocation are introduced.

Table 5.3: Division of supply-flows from the activities in **Figure 5.2** into reference flows, by-products and materials for treatment.

Supply-flows	**Activity A**	**Treatment activity I_1**	**Treatment activity I_2**
Reference products	A_{ref}	$I_{1,in}$	$I_{2,in}$
By-products	A_{by}	$I_{1,by}$	$I_{2,by}$
Materials for treatment	A_{treat}	$I_{1,treat}$	-

Switch: Substitution

The inventory of the three activities in **Figure 5.2** when applying substitution is described in this section. According to Suh et al. (2010) dependant by-products can be included as negative inputs of products in life cycle inventory. Modelling of outputs of materials for treatment is carried out by including the reference flow of the downstream treatment activity as an input to the supplying activity. The life cycle inventory of the flows of concern when applying substitution is illustrated in **Table 5.4**.

Table 5.4: Inventory of the activities in **Figure 5.2** when applying substitution.

Product name	Activity A	Treatment activity I_1	Treatment activity I_2
Reference products			
A_{ref}	$q_{A,ref}$		
$I_{1,in}$		$q_{I1,in}$	
$I_{2,in}$			$q_{I2,in}$
Inputs			
$I_{1,in}$	$q_{A,treat}$		
$I_{2,in}$		$I_{1,treat}$	
B_{ref}	$-q_{A,by}$		
C_{ref}		$q_{I1,by}$	
D_{ref}			$-q_{I2,by}$

Switch: Allocation type I

The inventory of the three activities in **Figure 5.2** when applying allocation type I is described in this section. Allocation is carried out at the point of substitution after the treatment activities. This means that activity A, I_1 and I_2 needs to be allocated together. In order to do so the by-products supplied by the treatment activities are moved up to activity A, and the treatment activities are included as inputs to activity A as in the case of substitution. The life cycle inventory of the flows of concern when applying substitution is illustrated in **Table 5.5**.

The allocation factors $af_{A,ref}$, $af_{A,by}$ and $af_{A,treat}$ are calculated as of **Equation 5.1** to **Equation 5.4**:

Equation 5.1

$$af_{A,ref} = \frac{au_{A,ref}}{au_{A,ref} + au_{A,by} + au_{I1,by} + au_{I2,by}}$$

$$= \frac{q_{A,ref} \cdot av_{A,ref}}{\left(q_{A,ref} \cdot av_{A,ref}\right) + \left(q_{A,by} \cdot av_{A,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot av_{I1,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot \frac{q_{I2,by}}{q_{I2,in}} \cdot av_{I2,by}\right)}$$

Equation 5.2

$$af_{A,by} = \frac{au_{A,by}}{au_{A,ref} + au_{A,by} + au_{I1,by} + au_{I2,by}}$$

$$= \frac{q_{A,by} \cdot av_{A,by}}{\left(q_{A,ref} \cdot av_{A,ref}\right) + \left(q_{A,by} \cdot av_{A,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot av_{I1,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot \frac{q_{I2,by}}{q_{I2,in}} \cdot av_{I2,by}\right)}$$

Equation 5.3

$$af_{I1,by} = \frac{au_{I1,by}}{au_{A,ref} + au_{A,by} + au_{I1,by} + au_{I2,by}}$$

$$= \frac{\left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot av_{I1,by}\right)}{\left(q_{A,ref} \cdot av_{A,ref}\right) + \left(q_{A,by} \cdot av_{A,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot av_{I1,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot \frac{q_{I2,by}}{q_{I2,in}} \cdot av_{I2,by}\right)}$$

Equation 5.4

$$af_{I2,by} = \frac{au_{I2,by}}{au_{A,ref} + au_{A,by} + au_{I1,by} + au_{I2,by}}$$

$$= \frac{\left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot \frac{q_{I2,by}}{q_{I2,in}} \cdot av_{I2,by}\right)}{\left(q_{A,ref} \cdot av_{A,ref}\right) + \left(q_{A,by} \cdot av_{A,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot av_{I1,by}\right) + \left(q_{A,treat} \cdot \frac{q_{I1,by}}{q_{I1,in}} \cdot \frac{q_{I2,by}}{q_{I2,in}} \cdot av_{I2,by}\right)}$$

The allocation values (av), e.g. prices of the flows, and the flow quantities in **Equation 5.1** to **Equation 5.4** are specified as part of data collection.

Table 5.5: Inventory of the activities in **Figure 5.2** when applying allocation type I.

Product name	Activity A+I_1+I_2 [A_{ref}]	allocated Activity A+I_1+I_2 [A_{by}]	Activity A+I_1+I_2 [I_{1by}]	Activity A+I_1+I_2 [I_{2by}]	Treatment activity I_1	Treatment activity I_2
Reference products						
A_{ref}	$q_{A,ref}$					
A_{by}		$q_{A,by}$				
$I_{1,by}$			$q_{I1,by}$			
$I_{2,by}$				$q_{I2,by}$		
$I_{1,in}$					$q_{I1,in}$	
$I_{2,in}$						$q_{I2,in}$
Inputs						
$I_{1,in}$	$af_{A,ref} \cdot q_{A,treat}$	$af_{A,by} \cdot q_{A,treat}$	$Af_{I1,by} \cdot q_{A,treat}$	$Af_{I2,by} \cdot q_{A,treat}$		
$I_{2,in}$					$q_{I1,treat}$	
All other inputs x	$x \cdot af_{A,ref}$	$x \cdot af_{A,by}$	$x \cdot af_{I1,by}$	$x \cdot af_{I2,by}$	x	x

Switch: Allocation type II

The inventory of the three activities in **Figure 5.2** when applying allocation type II is described in this section. Allocation is carried out before the treatment activities. The life cycle inventory of the flows of concern when applying substitution is illustrated in **Table 5.5**.

The allocation factors $af_{A,ref}$, $af_{A,by}$, $af_{A,treat}$, $af_{I1,by}$ and $af_{I1,treat}$ are calculated as of **Equation 5.5** to **Equation 5.9**:

Equation 5.5

$$af_{A,ref} = \frac{au_{A,ref}}{au_{A,ref}+au_{A,by}+au_{A,treat}} = \frac{q_{A,ref} \cdot av_{A,ref}}{(q_{A,ref} \cdot av_{A,ref})+(q_{A,by} \cdot av_{A,by})+(q_{A,treat} \cdot av_{A,treat})}$$

Equation 5.6

$$af_{A,by} = \frac{au_{A,by}}{au_{A,ref}+au_{A,by}+au_{A,treat}} = \frac{q_{A,by} \cdot av_{A,by}}{(q_{A,ref} \cdot av_{A,ref})+(q_{A,by} \cdot av_{A,by})+(q_{A,treat} \cdot av_{A,treat})}$$

Equation 5.7

$$af_{A,treat} = \frac{au_{A,treat}}{au_{A,ref}+au_{A,by}+au_{A,treat}} = \frac{q_{A,treat} \cdot av_{A,treat}}{(q_{A,ref} \cdot av_{A,ref})+(q_{A,by} \cdot av_{A,by})+(q_{A,treat} \cdot av_{A,treat})}$$

Equation 5.8

$$af_{I1,by} = \frac{au_{I1,by}}{au_{I1,by}+au_{I1,treat}} = \frac{q_{I1,by} \cdot av_{I1,by}}{(q_{I1,by} \cdot av_{I1,by})+(q_{I1,treat} \cdot av_{I1,treat})}$$

Equation 5.9

$$af_{I1,treat} = \frac{au_{I1,treat}}{au_{I1,by}+au_{I1,treat}} = \frac{q_{I1,treat} \cdot av_{I1,treat}}{(q_{I1,by} \cdot av_{I1,by})+(q_{I1,treat} \cdot av_{I1,treat})}$$

The allocation values (av), e.g. prices of the flows, and the flow quantities in **Equation 5.5** to **Equation 5.9** are specified as part of data collection.

Table 5.6: Inventory of the activities in **Figure 5.2** when applying allocation type I.

	allocated			allocated		allocated	
Product name	**Activity A [A_{ref}]**	**Activity A [A_{by}]**	**Activity A [A_{treat}]**	**Treatment activity I_1 [$I_{1,by}$]**	**Treatment activity I_1 [$I_{1,treat}$]**	**Treatment activity I_1**	**Treatment activity I_2**
Reference products							
A_{ref}	$q_{A,ref}$						
A_{by}		$q_{A,by}$					
A_{treat}			$q_{A,treat}$				
$I_{1,by}$				$q_{I1,by}$			
$I_{1,treat}$					$q_{I1,treat}$		
$I_{2,by}$						$q_{I2,by}$	
$I_{2,treat}$							$q_{I2,treat}$
Inputs							
All inputs x	$x \cdot af_{A,ref}$	$x \cdot af_{A,by}$	$x \cdot af_{A,treat}$	$x \cdot af_{I1,by}$	$x \cdot af_{I1,treat}$	$x \cdot af_{I2,by}$	$x \cdot af_{I2,treat}$

5.4 Switching between different levels of completeness

Completeness of product inputs to activities is handled through two parameters:

1. capital goods: parameter cg, parameter values $\in [0,1]$, where 0 means not included, and 1 means included
2. services: parameter sv, parameter values $\in [0,1]$, where 0 means not included, and 1 means included

The parameter cg is multiplied with all inputs of capital goods throughout the product system, and the parameter sv is multiplied with all inputs of services throughout the product system.

6 The cattle system

The target activity of Arla's model is the milk producing activity, i.e. the milk system. The following methodology for inventorying the cattle system can be applied to the individual farm level as well as national cattle systems.

6.1 Overview of the cattle system

The milk system is a subset of the cattle system which in general can be divided into a dairy and a meat system. It should be noted that production of grass, ensilage, grains and concentrates are modelled as being outside the cattle system. The dairy cow is the core activity in the milk system. The milk system also includes some additional activities (treatment activities) caused by the material for treatment supplied by the dairy cow, i.e. activities relating the calves and manure. Within the cattle system, the activities in **Table 6.1** are inventoried and accounted for separately in the model.

All systems in **Table 6.1** can be inventoried at any level (farm, national, regional, global). All systems are inventoried at the national level. However, in the current study only the milk system in **Table 6.1** is inventoried at the farm specific level.

Table 6.1: Included activities in the cattle system.

Activities within the cattle system	Description
Milk system	
Dairy cow	This activity includes the dairy cow. The product outputs are raw milk, calves, the live animal at end of live of the milk productive time, and manure. The product output of raw milk is the reference flow of the activity. The live animal after the productive life of the dairy cow is sent to slaughter house, and the calves can be sent to three different destinations: 1) they can be raised and sent to slaughter house, 2) they can be put down and sent to destruction, and 3) they can be raised and be used as input to the dairy cow activity. Manure is a material for treatment; see manure system in the bottom of the table.
Raising heifer for milk production	This activity is a treatment activity which includes the raising of the calf from new-born until it can be used in the milk system. The reference flow is heads of newborn heifers. The product output is heifers for milk production. Manure is a material for treatment; see manure system in the bottom of the table.
Raising newborn bull for meat production	This activity is a treatment activity which includes 1. the raising of the newborn calf until it is sent for further raising, and 2. the raising of the bull calf from (1) until it is ready for being sent to slaughter house The reason why the raising of bulls for meat production is divided in to two activities/stages is that the two stages are often different in terms of feed intake (large share of milk for newborn bulls vs. large share of feed for older bulls) and the two stages sometimes take place in different locations (e.g. on farm vs. intensive raising system). The product output from 1) is bull calves fur further raising, and the product output from 2) is cattle meat, as live weight. Manure is a material for treatment; see manure system in the bottom of the table.
Raising bull calf for meat production	
Beef system	
Suckler cow	This activity includes the suckler cows. The product outputs are calves, cattle meat as live weight, and manure. The reference flow of the activity is the sum of meat, as live weight, from the suckler cow, the raising of heifer calves, and the raising of bull calves. The raising of calves are treatment activities which are closely linked to the suckler cow activity by the number of born calves. Manure is a material for treatment; see manure system in the bottom of the table.
Raising heifer calf	These activities are a treatment activities which include the raising of the heifer/bull calves from new-born until they can be used as suckler cows (only heifer calves) or sent to slaughter house (heifer calves and bull calves). The reference flow is heads of newborn heifers/calves. The product outputs are heifers for suckler cows, meat as live weight, and manure. It should be noted that the meat product output is accounted as product output of the suckler cows in the inventory model. Manure is a material for treatment; see manure system in the bottom of the table.
Raising bull calf	
Manure system	
Manure treatment (manure from storage)	This activity is a treatment activity which includes the handling of manure from the point when it leaves the manure storage (after the stable) until it is transformed into emissions, products (substituting mineral fertiliser) or soil organic matter. The activity includes transportation and application to the field, and it may also include biogasification before land application.
Manure treatment (urine and dung deposited by grazing animals on pasture)	This activity is a treatment activity which includes the handling of urine and dung deposited on pasture from the point when it leaves the animal until it is transformed into emissions, products (substituting mineral fertiliser) or soil organic matter.
Destruction of fallen animals	This activity is a treatment activity which includes the destruction of fallen animals. The activity includes energy and material consumption related to the transformation of the dead animal into biofuels that substitute fossil fuels.

The cattle system described in **Table 6.1** supplies several product outputs where the two major ones are raw milk and cattle meat. In addition a number of intermediate transactions between the activities are present. The transactions within the milk system and the beef system are illustrated in **Figure 6.1** and **Figure 6.2** respectively.

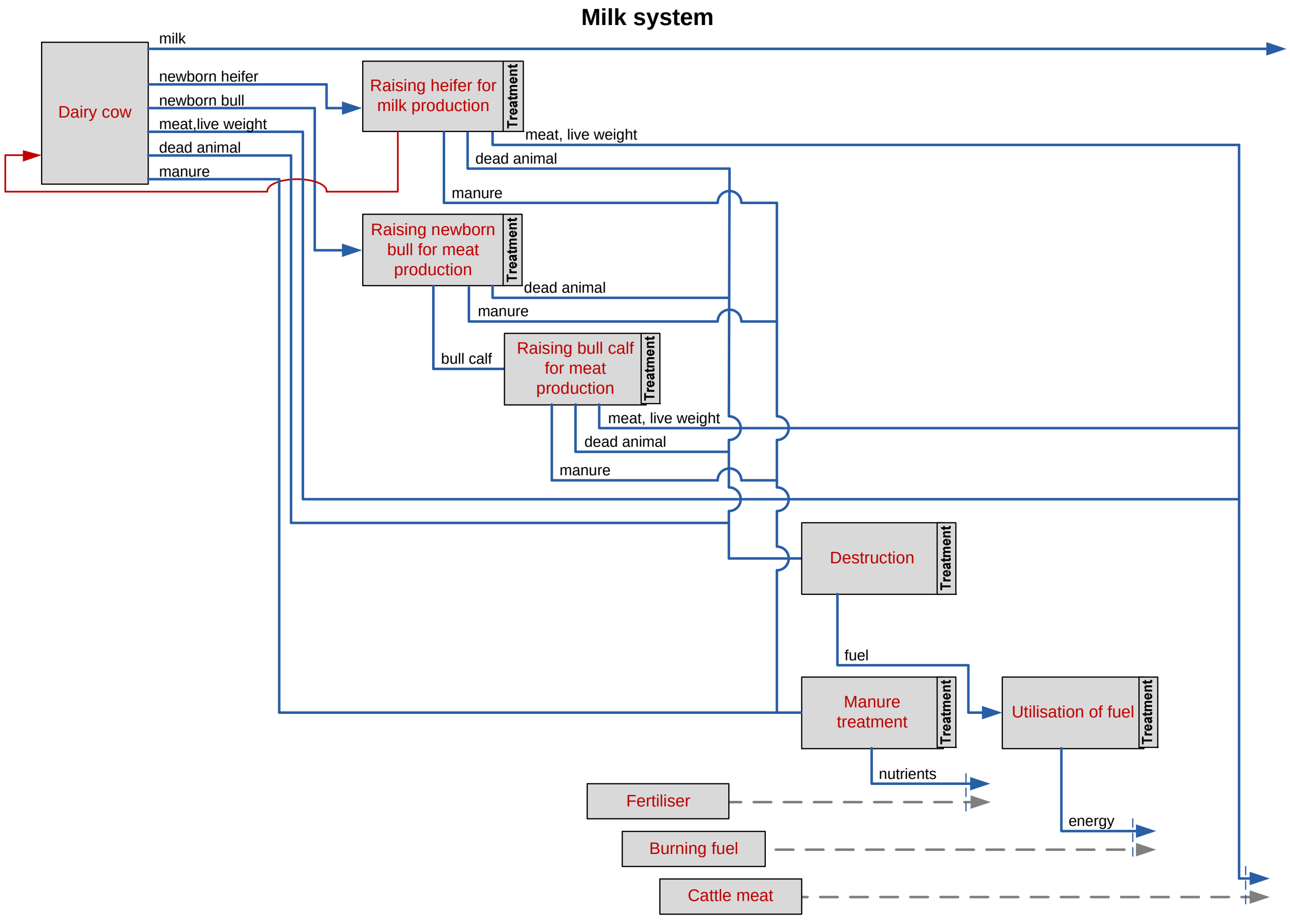


Figure 6.1: Overview of the transactions within the milk system and downstream for by-products and materials for treatment until the point of substitution.

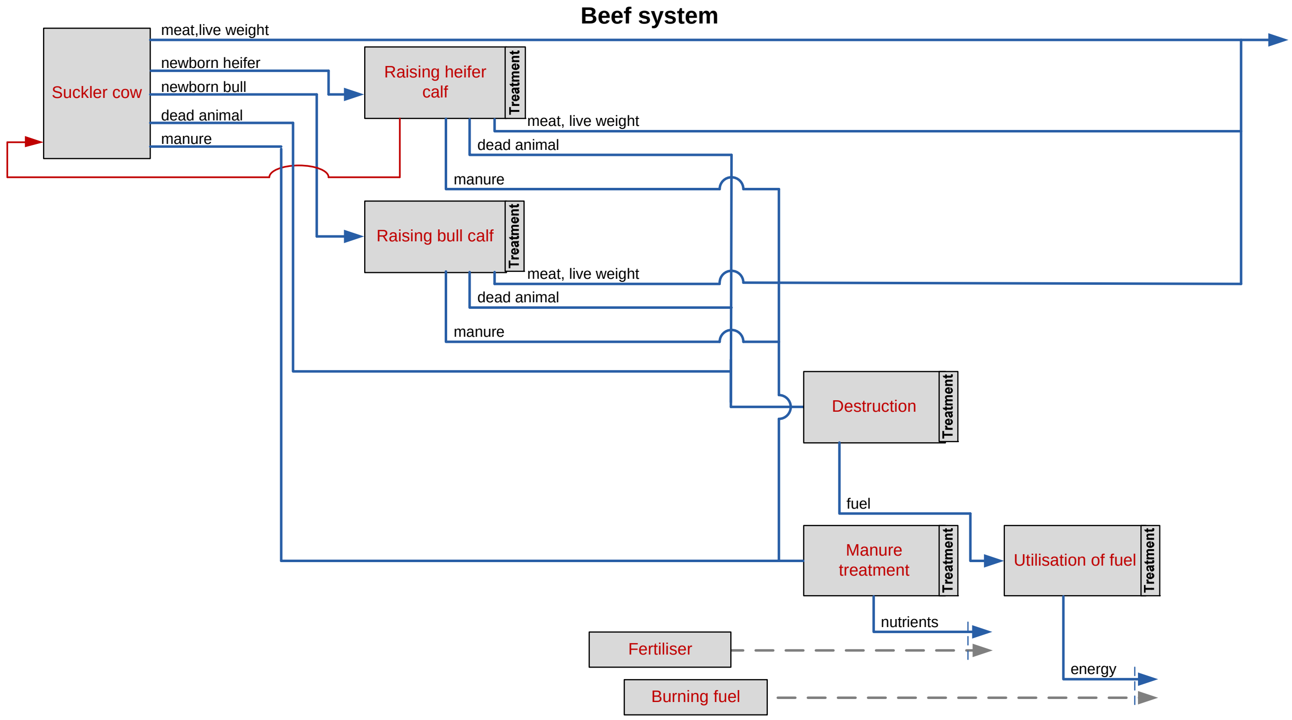


Figure 6.2: Overview of the transactions within the beef system and downstream for by-products and materials for treatment until the point of substitution.

6.2 Market delimitation of products supplied by the cattle system

The products in **Table 6.1** may be traded on common markets or on differentiated markets. This section considers the differentiation of the markets on which the products in the bovine system are traded.

Geographical delimitation

Since the milk system is the target system of the model in the present study, the geographical location of the milk system is by definition the location being studied, i.e. national baseline or a specific farm in a country.

A significant dependant co-product of the milk system is cattle meat (see **Table 6.1**). Thus, in cases where this co-product is modelled using substitution, the displaced cattle meat system needs to be identified. The geographical location of this system is not necessary in the same country/location as the milk system.

According to FAOSTAT (2012) the domestic production of cattle meat in the European Union in 2005 is 14.7 million tonne live weight (carcass weight to live weight ratio at 0.55 is used). It can be roughly estimated that 7.3 million tonne of the 14.7 million tonne is produced as a by-product in the milk system. This is estimated by multiplying the total production of raw milk at 149 million tonne in 2005 (FAOSTAT 2012) by a meat (live weight) to raw milk ratio at 0.049 (estimated as an average of the Danish and Swedish milk systems).

The 7.3 million tonne cattle meat from the milk system is considered as being constrained by the demand for milk. Only the cattle meat production from the beef system is considered as being flexible. This can be estimated as 14.7 million tonne minus 7.3 million tonne = 7.4 million tonne.

The import of cattle meat to the European Union in 2005 is 1.53 million tonne (live weight). The total supply of flexible cattle meat is 7.4 million tonne (domestic production) plus 1.5 million tonne import = 8.9 million tonne. The import share of the supply of flexible cattle meat is then 17%. Based on this figure, the market for cattle meat in Europe is not considered as being limited to Europe, and it is assumed that the market is global. Hence, the marginal supplier of cattle meat is to be identified on the global market.

In **Table 6.2** below, the trend and production of cattle meat from the beef system is indicated for the top-five countries with the highest trend for different periods. The trend is regarded as being a good indicator for countries competiveness. According to Weidema et al. (2009), the marginal supplier can generally be identified as the most competitive supplier among those suppliers which are flexible.

Table 6.2: Trend and production of cattle meat from the beef system. Figures are shown for the top-five countries with the highest trend for different periods. The figures are based on FAOSTAT (2012) for cattle meat and milk production. The cattle meat from the milk system is estimated by using a meat (live weight) to raw milk ratio at 0.049, and carcass weight from FAOSTAT is transformed to live weight by use of a carcass to live weight ratio at 0.55.

Country	Trend 1995-2000 (mill t yr-1)	Production 2000 (mill t)
China	0.60	8.3
Brazil	0.23	11.0
USA	0.19	18.6
Canada	0.13	1.9
Australia	0.07	3.1

Country	Trend 2000-2005 (mill t yr-1)	Production 2005 (mill t)
Brazil	0.63	14.4
Argentina	0.21	5.2
Sudan	0.20	1.3
Canada	0.09	2.3
Uruguay	0.06	1.0

Country	Trend 2005-2010 (mill t yr-1)	Production 2010 (mill t)
China	0.24	9.6
Sudan	0.22	2.5
USA	0.17	17.6
Mexico	0.06	2.6
Viet Nam	0.05	0.5

Country	Trend 1995-2010 (mill t yr-1)	Production 2010 (mill t)
Brazil	0.21	9.6
China	0.20	2.5
Sudan	0.17	17.6
Argentina	0.07	2.6
South Africa	0.05	0.5

It appears from the different figures in **Table 6.2**, that the identification of the margin supplier of beef is highly influenced by the period for which the trend is calculated. However, Brazil appears to the the country with the highest trend for the whole period from 1995-2010, and Brazil also appears to be the country with second highest and highest trend for 1995-2000 and 2000-2005 respectively. Based on this, the marginal supplier of beef is identified as Brazil.

It is evident that this identification is related to significant uncertainties. Therefore, sensitivity analyses will be presented where Danish beef is substituted caused by the beef production by the Danish milk system and correspondingly, where Swedish beef is substituted caused by the beef production by the Swedish milk system.

Temporal delimitation

For the cattle system, there is no relevant temporal segmentation; demand can be assumed to be stable over seasons and during day and night time. Of course the nature of the bovine system develops over time; but this is not what is concerned by temporal delimitation.

Consumer segments

In general, the products in **Figure 6.2** are not differentiated on different markets related to consumer segments. There are some exceptions, where the most relevant is the market for 'bovine meat, as live weight' where it may be possible to identify separate markets differentiated by quality of the bovine meat. The quality of the bovine meat from the bovine meat system is regarded as being higher than of the milk system. However, it has not been possible identifying information that supports the fact that 1 kg bovine meat from the milk system is not substitutable (and will not displace in reality) meat of the meat system. Therefore, it is assumed that 1 kg tenderloin, fillet or minced meat etc. from the bovine system displaces 1 kg tenderloin, fillet or minced meat etc. respectively in a ratio 1:1. There may exist some special high quality bovine meat system that supplies high quality meat to a consumer segment for this type of meat. This segment is not presumed affected, and when using average data on the meat system, it is assumed that this special high quality bovine meat system is small compared to the bovine meat system supplying normal quality meat.

6.3 Inventory of feed inputs to the cattle system

One of the major challenges of the inventory cattle sector is related to the determination of inputs of feed. Inventory data on the transactions of milk, meat and calves are obtained directly from national statistics/agricultural models and from the specific dairy cow farms using the model.

In the following the method for inventory of the use of feed is described. The method applies to national dairy cow and beef systems as well as farm specific dairy com systems.

The inventory of feed inputs includes 1) the determination of total feed use, and 2) distribution of this total on different feedstuffs.

Determination of total feed use

There exist different models for estimating the total feed use of cattle systems. For this purpose, it has been chosen to use the method for estimating net energy in IPCC (2006, section 10.2) as default, see **Equation 6.1** below.

Equation 6.1

$$\mathrm{NE} = \mathrm{NE_m} + \mathrm{NE_a} + \mathrm{NE_l} + \mathrm{NE_{work}} + \mathrm{NE_p} + \mathrm{NE_g}$$

Where:

NE = total net energy, MJ day-1
NE_m = net energy required by the animal for maintenance, MJ day-1 (see **Equation 6.9**)
NE_a = net energy for animal activity, MJ day-1 (see **Equation 6.10**)
NE_l = net energy for lactation, MJ day-1 (see **Equation 6.11**)
NE_{work} = net energy for work, MJ day-1 (see **Equation 6.12**)
NE_p = net energy required for pregnancy, MJ day-1 (see **Equation 6.13**)
NE_g = net energy needed for growth, MJ day-1 (see **Equation 6.15**)

The IPCC method as of **Equation 6.1** 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. For Denmark such data for dairy cows have been developed and refined by Kristensen (2011), see **Equation 6.2**. The model provided by Kristensen (2011) establishes a correlation between feed intake and milk yield for Danish conditions. The model is based on Østergaard (1989) and has been revised based on milk yields and feed intake in 1997, 2006 and 2010.

Equation 6.2

$$\mathrm{FEreq} = 7.82 \cdot \left(2002 + 360 \cdot \frac{\mathrm{ECM}}{1000} + 17.5 \cdot \left(\frac{\mathrm{ECM}}{1000}\right)^2\right)$$

Where:

FEreq = feed energy intake, MJ net energy
ECM = energy corrected milk, kg
7.82 = Scandinavian feed unit (SFU) to net energy conversion factor, MJ net energy SFU-1. The factor is obtained from Volden (2011).

It has been chosen to use the Danish model for dairy cows in Denmark and Sweden, and the IPCC model for the remaining cattle activities. The reason why the Danish model is used in Sweden is that 1) the conditions in Sweden are considered similar to Denmark, and 2) two different models in two different countries could bias the one country over the other if one of the models tends to over or under estimate the feed intake. In **Table 6.3**, the calculated net energy feed intake by the two models are shown for dairy cows in Denmark and Sweden. It appears from the comparison that the two models generally are in good agreement.

Table 6.3: Comparison of the feed net energy intake per cow per day in Denmark and Sweden calculated by the IPCC model and by the Danish model. The parameters used in the calculations are documented in the inventory report (Dalgaard and Schmidt 2012).

Net energy feed intake for dairy cows	Net energy, MJ cow-1 day-1 Denmark 2005	Net energy, MJ cow-1 day-1 Sweden 2005
IPCC method (IPCC 2006, section 10.2)	128	124
Danish model (Kristensen 2011)	135	132

For some calculations, e.g. enteric fermentation and methane emissions from manure management, the gross energy (GE) is needed. Hence, the net energy (NE) needs to be converted to gross energy (GE). Two approaches for this have been identified: 1) to use equations provided in IPCC (2006, section 10.2) or to calculate the gross energy based on the use of each feedstuff and their content of raw protein, fat and carbohydrate (by use of **Equation 6.3**).

Equation 6.3

$$\mathrm{GE} = 24.1 \cdot \mathrm{raw\ protein} + 36.6 \cdot \mathrm{fat} + 18.5 \cdot \mathrm{carbohydrate}$$

Where:

GE = gross energy, MJ
Raw protein = protein content, kg kg dm-1
Fat = fat content, kg kg dm-1
Carbohydrate = carbohydrate content, kg kg dm-1

In **Table 6.4**, the net to gross energy by the two models is shown for dairy cows in Denmark and Sweden. The comparison shows that the two models generally are in good agreement.

Table 6.4: Comparison of the net to gross energy feed intake ratio in Denmark and Sweden calculated by the IPCC model and by the feed properties of the input of different feedstuff. The parameters used in the calculations are documented in the inventory report (Dalgaard and Schmidt 2012).

Gross energy intake for dairy cows	Net to gross energy ratio Danish dairy cows 2005	Net to gross energy ratio Swedish dairy cows 2005
IPCC method (IPCC 2006, section 10.2)	40%	40%
Gross energy based on feed properties	39%	37%

It is chosen to calculate the gross energy by use of the feedstuff properties.

Distribution of the total feed on different feedstuffs

When collecting data on feedstuff inputs to the cattle systems, some of the feed inputs are obtained directly from national statistics/agricultural models and from the specific dairy cow farms using the model. However, not all feed inputs are known. The yields of roughage cultivation are seldom known. This applies to the national as well as the farm level. Therefore, the inputs of roughage are estimated based on total feed requirement (energy and protein) and the specified inputs of feed.

The total feed requirement (feed energy) for a farm or national milk system or beef system is calculated using **Equation 6.1** or **Equation 6.2**. Furthermore, the total feed protein requirement is calculated based on knowledge on the overall protein to energy relationship in feed plans. The use of roughage is then be calculated by establishing a relationship between the total feed energy and protein in roughage and the energy and protein content in different types of roughage. The total energy and protein in roughage is be calculated as the difference between the total energy and protein requirement and the energy and protein in other feedstuff, i.e. grain, oil meals etc.

The model distinguishes three types of roughage; maize ensilage, rotation grass ensilage and permanent grass. Since the approach for determining the use of roughage as explained above enables for the establishment of two equations with two unknowns, then one of the three roughages has to be specified. The remaining two can be calculated by using **Equation 6.4**. Since permanent grass is related to substantial different emissions than cultivation of maize and grass ensilage, it is chosen that permanent grass is the type of roughage to be specified. The main difference between maize and rotation grass ensilage is the content of protein; grass (and especially clover grass) contains more protein relative to feed energy than maize. Therefore, **Equation 6.4** provides a meaningful relationship between the parameters determining the calculated use of maize and rotation grass ensilage.

Equation 6.4

$$\text{e\_cont}_{em} \cdot \text{em} + \text{e\_cont}_{rg} \cdot \text{rg} = \text{FEreq\_re}$$
$$\text{p\_cont}_{em} \cdot \text{em} + \text{p\_cont}_{rg} \cdot \text{rg} = \text{FPreq\_re}$$

where:

e_cont = content of net energy, MJ net energy per kg dry matter roughage, the subscripts em and rg refer to ensilage maize (em) and rotation grass (rg) respectively
p_cont = content of protein, kg protein per kg dry matter roughage, the subscripts em and rg refer to ensilage maize (em) and rotation grass (rg) respectively
FEreq_re = feed energy requirement from maize and rotation grass roughage, MJ net energy
FPreq_re = feed protein requirement from maize and rotation grass roughage, kg protein
em = ensilage maize, kg dry matter
rt = rotation grass, kg dry matter

The terms 'FEreq_re' and 'FPreq_re' in **Equation 6.4** are calculated as of **Equation 6.5**.

Equation 6.5

FEreq_re = FEreq – imported feed energy – home grown grain and permanent grass energy
FPreq_re = FPreq – imported feed protein – home grown grain and permanent grass protein

where:

FEreq_re = feed energy requirement from maize and rotation grass roughage, MJ net energy
FPreq_re = feed protein requirement from maize and rotation grass roughage, kg protein
FEreq = total feed energy requirement, MJ net energy
FPreq = total feed protein requirement, kg protein

By substitution or Gauss-Jordan, the two equations in **Equation 6.4** can solved for em and rg as of **Equation 6.6**.

Equation 6.6

$$\mathrm{em} = \frac{\left(\mathrm{FEreq\_re} - \dfrac{\mathrm{e\_cont_{rg}} \cdot \mathrm{FPreq\_re}}{\mathrm{p\_cont_{rg}}}\right)}{\left(\mathrm{e\_cont_{em}} - \dfrac{\mathrm{e\_cont_{rg}} \cdot \mathrm{p\_cont_{em}}}{\mathrm{p\_cont_{rg}}}\right)}$$

$$\mathrm{rg} = \frac{\left(\mathrm{FEreq\_re} - \dfrac{\mathrm{e\_cont_{em}} \cdot \mathrm{FPreq\_re}}{\mathrm{p\_cont_{em}}}\right)}{\left(\mathrm{e\_cont_{rg}} - \dfrac{\mathrm{e\_cont_{em}} \cdot \mathrm{p\_cont_{rg}}}{\mathrm{p\_cont_{em}}}\right)}$$

The total list of inventoried feedstuff inputs to cattle farms includes the following categories. The included feedstuff represents >95% of the total use of feedstuff for cattle in Denmark and Sweden respectively in 2005. The identification of the >95% for Denmark is based on data in Mogensen (2011) and for Sweden it is based on Cederberg (2009a).

- Imported Barley
- Imported Wheat
- Imported Oat
- Imported Corn
- Imported Soybean meal
- Imported Rapeseed cake/meal
- Imported Sunflower meal
- Imported Beet pellets
- Imported Beet pulp
- Imported Molasses
- Imported Palm oil
- Imported Palm kernel meal
- Imported Wheat bran
- Imported Feed urea
- Imported Minerals, salt etc.
- Home grown Barley
- Home grown Wheat
- Home grown Oat
- Home grown Permanent grass
- Home grown Maize ensilage
- Home grown Rotation grass

The two last categories in the list above (red text) are the ones calculated using **Equation 6.6**. The remaining categories, i.e. imported feed and home grown grain and permanent grass, is what is referred to as FEreq_re and FPreq_re in **Equation 6.5**.

When collecting data on feed inputs, this is done at the system level, i.e. for all activities within the milk system and the beef system respectively (see activities in **Table 6.1**). The reason for this is that when a farmer purchases or cultivates feed it is not known whether this is used by cows, bulls or heifers. When data on the total data feed intake per system are collected, the total is distributed in the activities within each system by use of the calculated feed energy requirement (FEreq).

6.4 Inventory of methane from enteric fermentation

Enteric fermentation result in emissions of methane. The methodology of IPCC (2006) will be used to quantify these emissions, because the methodology is internationally accepted, well-funded and requires a limited number of data. For methane emissions the Tier 2 approach (more detailed compared to Tier 1) is be applied to increase the ability to capture the differences between countries and between specific farms. Other methods for quantification of methane from enteric fermentation exist, but these in general require a much more detailed data input.

Methane from enteric fermentation is calculated from **Equation 6.7** (IPCC 2006, equation 10.21).

Equation 6.7

$$EF = \left[\frac{GE \cdot \frac{Y_m}{100} \cdot 365}{55.65}\right]$$

Where:

EF = emission factor, kg CH4 head-1 yr-1

GE = gross energy intake, MJ head-1 day-1 (see **Equation 6.2** for dairy cows and **Equation 6.3** for other cattle)

Y_m = methane conversion factor, per cent of gross energy in feed converted to methane. The value Y_m is determined using IPCC (2006, Table 10.12)

The factor 55.65 (MJ/kg CH4) is the energy content of methane

It should be noted that IPCC (2006, section 10.2) suggests to use equation **Equation 6.8** for the calculation of gross energy parameter in **Equation 6.7**. However, as discussed in **section 6.3**, the gross energy is calculated based on the use of different feedstuff and its content of protein, fat and carbohydrate. Despite the fact that **Equation 6.8** is not used, it is documented extensively here anyway. The reason for this is, that the parameters of net energy (NE) in **Equation 6.8** are used for calculating the net energy feed intake by non-dairy cows.

Equation 6.8

$$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM}\right) + \left(\frac{NE_g}{REG}\right)}{\frac{DE\%}{100}}\right]$$

(IPCC 2006, equation 10.16)

Where:

GE = gross energy intake, MJ head-1 day-1

NE_m = net energy required by the animal for maintenance, MJ day-1 (see **Equation 6.9**)

NE_a = net energy for animal activity, MJ day-1 (see **Equation 6.10**)

NE_l = net energy for lactation, MJ day-1 (see **Equation 6.11**)

NE_{work} = net energy for work, MJ day-1 (see **Equation 6.12**)

NE_p = net energy required for pregnancy, MJ day-1 (see **Equation 6.13**)

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (see **Equation 6.14**)

NE_g = net energy needed for growth, MJ day-1 (see **Equation 6.15**)

REG = ratio of net energy available for growth in a diet to digestible energy consumed (see **Equation 6.16**)

DE%= digestible energy expressed as a percentage of gross energy

The derivation of the parameters in **Equation 6.8** is described in the following **Equation 6.9** to **Equation 6.16**.

Equation 6.9

$$NE_m = Cf_i \cdot weight^{0.75}$$

(IPCC 2006, equation 10.3)

Where:

NE_m = net energy required by the animal for maintenance, MJ day-1
Cfi = a coefficient which varies for each animal category, MJ day-1 kg-1. The value of Cf_i is determined using IPCC (2006, Table 10.4)
Weight = live-weight of animal, kg

Equation 6.10

$$NE_a = C_a \cdot NE_m$$

(IPCC 2006, equation 10.8)

Where:

NE_a = net energy for animal activity, MJ day-1
C_a = coefficient corresponding to animal's feeding situation. The value of C_a is determined using IPCC (2006, Table 10.5)
NE_m = net energy required by the animal for maintenance, MJ day-1 (see **Equation 6.9**)

Equation 6.11

$$NE_l = milk \cdot (1.47 + 0.40 \cdot fat)$$

(IPCC 2006, equation 10.8)

Where:

NE_l = net energy for lactation, MJ day-1
Milk = amount of milk produced, kg of milk day-1
Fat = fat content of milk, % by weight.

Equation 6.12

$$NE_{work} = \text{this is not relevant for commercial milk and beef cattle}$$

Equation 6.13

$$NE_p = C_{pregnancy} \cdot NE_m$$

(IPCC 2006, equation 10.13)

Where:

NE_p = net energy required for pregnancy, MJ day-1
$C_{pregnancy}$ = pregnancy coefficient. The value of $C_{pregnancy}$ is determined using IPCC (2006, Table 10.7)
NE_m = net energy required by the animal for maintenance, MJ day-1 (see **Equation 6.9**)

Equation 6.14

$$\text{REM} = \left[1.123 - (4.092 \cdot 10^{-3} \cdot \text{DE\%}) + [1.126 \cdot 10^{-5} \cdot (\text{DE\%})^2] - \frac{25.4}{\text{DE\%}}\right]$$

(IPCC 2006, equation 10.14)

Where:

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

Equation 6.15

$$\text{NE}_\text{g} = 22.02 \cdot \left(\frac{\text{BW}}{\text{C} \cdot \text{MW}}\right)^{0.75} \cdot \text{WG}^{1.097}$$

(IPCC 2006, equation 10.6)

Where:

NE_g = net energy needed for growth, MJ day-1
BW = the average live body weight (BW) of the animals in the population, kg
C = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls
MW = the mature live body weight of an adult female in moderate body condition, kg
WG = the average daily weight gain of the animals in the population, kg day-1

Equation 6.16

$$\text{REG} = \left[1.164 - (5.160 \cdot 10^{-3} \cdot \text{DE\%}) + [1.308 \cdot 10^{-5} \cdot (\text{DE\%})^2] - \frac{37.4}{\text{DE\%}}\right]$$

(IPCC 2006, equation 10.15)

Where:

REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

6.5 Inventory of methane and nitrous oxide emissions from manure management (stable and storage)

Handling/storage of manure results in emissions of methane and nitrous oxide. The methodology of IPCC (2006) is used to quantify these emissions, because this is internationally accepted, well-funded and requires a limited number of data. For methane emissions the Tier 2 approach (more detailed compared to Tier 1) will be applied to increase the ability to capture the differences between countries and between specific farms.

The type of manure management system highly influences the amount of methane and N_2O emitted from the manure. For example the emissions factors are higher for deep bedding systems compared to slurry systems. **Table 6.5** presents the distribution of manure types (slurry/solid/deep litter) within each manure management system. Data are from Illerup et al. (2005, p. 363). 'Deep litter systems' provide 100% deep litter or 50/50% slurry/deep litter if slatted floor is integrated in the system. 'Loose holding with beds systems' solely provide slurry. The percentages of manure nitrogen that volatilises as NH_3 and NO_x (FracGasMS) is used for calculation of indirect nitrous oxide (**Equation 6.24**) and are from Poulsen et al. (2001, Table 8.3). The effect of scrapes is not taking into account for calculation of NH_3 emissions. The $Frac_{GasMS}$ presented in **Table 6.5** only includes ammonia evaporated from the housing and not from the storage. This is included in the calculations by assuming 2% and 6% of N ab stable is evaporated from a covered and non-covered storage respectively (Hansen et al. 2008, Table 1). The prevalence of each manure management system in the respective countries is presented in the inventory report (Dalgaard and Schmidt 2012).

Table 6.5: Manure management systems used for cattle production. Sources: Illerup et al. (2005, p.363) and Poulsen et al. (2001, Table 8.3).

Manure management system (MMS) Denmark and Sweden	Manure types % Slurry/Solid/Deep litter	$Frac_{GasMS}$ % of N excreted
Deep litter (all)	0/0/100	6
Deep litter (boxes)	0/0/100	6
Deep litter, long eating space	0/0/100	6
Deep litter, slatted floor	50/0/50	7
Deep litter, slatted floor, scrapes	50/0/50	7
Deep litter, solid floor	0/0/100	6
Deep litter, solid floor, scrapes	50/0/50	7
Loose-holding with beds, slatted floor	100/0/0	8
Loose-holding with beds, slatted floor, scrapes	100/0/0	8
Loose-holding with beds, solid floor	100/0/0	10
Loosing-holding with beds, solid floor with tilt	100/0/0	10
Slatted floor-boxes	100/0/0	8
Tethered urine and solid manure	50/50/0	5
Tethered with slurry	100/0/0	3

Methane emissions from manure management

Methane is emitted from manure excreted by the cattle. Climate, manure management system and amount of manure excreted are all variables, which have an impact on the amount of methane emitted.

According to IPCC (2006, p. 10.41, Eq. 10.23), methane emitted per animal per year from manure management can be calculated as:

Equation 6.17

$$EF_{(T)} = (VS_{(T)} \times 365) \times \left[B_{o(T)} \times 0.67\ \mathrm{kg/m^3} \times \sum_{S,k} \frac{MCF_{S,k}}{100} \times MS_{(T,S,k)} \right]$$

Where:

$EF_{(T)}$ = annual CH_4 emissions factor for livestock category T, kg CH_4 animal^{-1} year^{-1}
$VS_{(T)}$ = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}. See **Equation 6.18**
365 = basis for calculating annual VS production, days year^{-1}
$B_{o(T)}$= maximum methane producing capacity for manure produced by livestock category, m^3 CH_4 (kg VS excreted)$^{-1}$
0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
$MCF_{(S,K)}$ = methane conversion factors for each manure management system S in climate region K, dimensionless
$MS_{(T,S,k)}$ = fraction of livestock category T's manure handled using system S in climate region K, dimensionless

The methane conversion factors (MCF) reflect the portion of maximum methane producing capacity ($B_{o(T)}$) achieved and vary with manure management system and climate. The higher MCF, the more methane is emitted. Manure management systems with deep bedding stored for more than one month have a higher MCF (=0.17 at $T \leq 10$ °C) compared to manure management system with liquid/slurry (MCF =0.10 $T \leq 10$ °C). On the other hand, if the deep bedding is stored for less than one month (which not is considered to be the case in Sweden and Denmark) MCF is low (=0.03 at $T \leq 10$ °C). MCF increases with the temperature, e.g. MCF for manure management system with liquid/slurry is five times higher at 28 °C compared to MCF at 10 °C. All things being equal, manure management systems in warm climates will emit most methane. The types of manure provided by each of the manure management systems are presented in **Table 6.5**.

The amount of daily volatile solid excreted (VS) highly influences the amount of methane emitted from the manure management systems. Volatile solids are the organics material in livestock manure and consist of both the biodegradable and non-biodegradable fraction (IPCC 2006, p. 10.42). A high feed consumption and a low digestibility of feed result in high VS and thereby a high methane emission. According to IPCC (2006, p. 10.42, Eq. 10.24), the VS excretion rate can be estimated as:

Equation 6.18

$$\mathrm{VS} = \left[\mathrm{GE} \times \left(1 - \frac{\mathrm{DE\%}}{(100)}\right) + (\mathrm{UE} \times \mathrm{GE})\right] \times \left[\frac{1 - \mathrm{ASH}}{18.45}\right]$$

Where:

VS = daily volatile solid excreted, kg dry matter animal^{-1} year^{-1}
GE= gross energy intake, MJ day^{-1} (see **Equation 6.1** for non-dairy cows and **Equation 6.2** for dairy cows)
DE% = digestibility of feed in percent (this is calculated as a weighted average of DE% for each of the used feedstuffs)
UE × GE = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants.
ASH = the ash content of manure calculated as a fraction of the dry matter feed intake.
18.45 = conversion factor for dietary GE per kg of dry matter, MJ kg^{-1}

Nitrous oxide emissions from manure management

N_2O emitted from manure primarily depends on the amount of N excreted by the cattle and the type of manure systems. N_2O emissions can be separated into direct and indirect emission. Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen in manure. Indirect N_2O emissions come from volatile nitrogen losses that occur primarily in the forms of ammonia and NOx. In general, the contribution from direct N_2O emissions is highest. The total amount of N_2O emitted from manure systems is calculated as the sum of direct N_2O and indirect N_2O:

Equation 6.19

$$N_2O_{(mm)} = N_2O_{D(mm)} + N_2O_{G(mm)}$$

Where:

$N_2O_{(mm)}$ = N_2O emissions from Manure Management, kg N_2O year^{-1}
$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management, kg N_2O year^{-1}
$N_2O_{G(mm)}$ = indirect N_2O emissions from Manure Management, kg N_2O year^{-1}

N_2O emissions from cattle manure excreted outdoor are not included in the cattle system. These emissions are part of the manure treatment system (see **section 6.6**) and the crop cultivation system (see **section 7.4**).

Direct N_2O

The calculation of direct N_2O emissions from manure management is based on IPCC (2006, p. 10.54, Eq. 10.25):

Equation 6.20

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \times Nex_{(T)} \times MS_{(T,S)} \right) \right] \times EF_{3(S)} \right] \times \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = direct N_2O emissions from manure management, kg N_2O year^{-1}
N_T = number of head of livestock species/category T in the activity
$Nex_{(T)}$ = annual N excretion per head of category T in the country, kg N animal^{-1}year^{-1}
$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system S, dimensionless
$EF_{3(S)}$ = emissions factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S

The type of manure management system highly influences the N_2O emissions as it was seen for the methane emission. The emissions factor for direct N_2O emissions ($EF_{3(S)}$) is 0.005 kg N_2O-N/kg N for liquid, slurry and solid storage, whereas it is double as much (=0.01) for deep bedding. If the deep bedding is active mixed, it is 0.07. It is considered not to be common practise to mix the deep bedding in Denmark and Sweden. The types of manure provided by each of the manure management systems are presented in **Table 6.5**.

An increase in annual N excretion per head (Nex) will increase the N_2O emission. In general dairy cows with high milk yield also excrete more N in manure. On the other hand, a cow which produces milk very efficiently and has a high milk yield per kg Nex, will also give rice to less N20 emission per kg milk from manure management system.

The amount of N excreted is calculated by use of the following equation:

Equation 6.21

$$\mathrm{Nex}_{(T)} = \mathrm{N}_{\mathrm{intake(T)}} - \mathrm{N}_{\mathrm{retention\ (T)}}$$

Where:

$Nex_{(T)}$ = annual N excretion per head of category T in the country, kg N animal^{-1}year^{-1}

$N_{intake(T)}$ = the annual N intake per head of animal of category T, kg N animal^{-1}year^{-1}

$N_{retention(T)}$ = the annual N retention per head of animal of category T, kg N animal^{-1}year^{-}

$N_{intake(T)}$ is calculated on basis of the protein content of the feed, whereas the amount of N retained in the milk and in the body mass of the cattle is subsequently calculated:

Equation 6.22

$$\mathrm{N}_{\mathrm{retention}} = \mathrm{N}_{\mathrm{milk}} + \mathrm{N}_{\mathrm{weight\ gain}}$$

Where:

$N_{retention(T)}$ = the annual N retention per head of animal of category T, kg N animal^{-1}year^{-}

N_{milk} = the annual amount of N in milk, kg N animal^{-1}year^{-1}

$N_{weight\ gain}$ = the annual N contained in weight gain, kg N animal^{-1}year^{-1}

N_{milk} is calculated by multiplying the amount of raw milk by the protein content (34.2 g per kg raw milk). $N_{weight\ gain}$ is calculated by multiplying the weight gain (weight of animal leaving minus weight of animal entering the activity) by 26 g N per kg living weight, which is the N-content of livings cattle according to Poulsen and Kristensen (1997, p. 18).

Indirect N_2O

According to IPCC (2006) indirect N_2O primarily derive from volatile nitrogen losses in the form of ammonia and NO_x. However, indirect N_2O is also formed from nitrogen runoff and leaching into soils from the solid storage of manure at outdoor areas, in feedlots and where animals are grazing in pastures. In the countries considered in this report, nitrogen runoff and leaching into soils from the stable and nearest surroundings is assumed to be negligible and is therefore not included in the calculation. The indirect N_2O emission from ammonia and NO_x is calculated according to IPCC (2006, p. 10.56, Eq. 10.27):

Equation 6.23

$$\mathrm{N_2O_{G(mm)}} = (\mathrm{N}_{\mathrm{volatilization\text{-}MMS}} \times \mathrm{EF}_4) \times \frac{44}{28}$$

Where:

$N_2O_{G(mm)}$ = indirect N_2O emissions from Manure Management, kg N_2O year^{-1}

$N_{volatilization\text{-}MMS}$ = amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N year^{-1}

EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$

44/28 = factor for conversion from N to N_2O

$N_{volatilization\text{-}MMS}$ is calculated according to IPCC (2006, p. 10.54, Eq. 10.26):

Equation 6.24

$$N_{\text{volatilization-MMS}} = \left[\sum_{S}\left[\sum_{T}\left(N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}\right) \times \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right]$$

Where:

$N_{volatilization\text{-}MMS}$ = amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N year^{-1}

EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$

N_T = number of head of livestock species/category T in the country

$Nex_{(T)}$ = annual N excretion per head of category T in the country, kg N animal^{-1}year^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system S, dimensionless

$Frac_{GasMS}$ = percent of managed manure nitrogen for livestock category T that volatilises as NH_3 and NO_x in the manure management system s, %. See **Table 6.5.**

According to IPCC (2006, p. 10.54) most of the N volatilized is in the form of NH_3. In this study it is assumed the amount of NOx emitted from manure management is negligible and is therefore not included in the calculations. Consequently, $Frac_{GasMS}$ only includes NH_3.

Indirect N_2O emission varies with the amount of annual N excreted per head ($Nex_{(T)}$) as it was seen for methane and direct N_2O emission. More NH3 is emitted from Loose-holdings systems with beds (0.08-0.10 kg NH_3-N per kg N) compared to tethered systems (0.03-0.05 kg NH_3-N per kg N) (Poulsen et al. (2001, Table 8.3).

6.6 Inventory of manure treatment (land application and utilisation)

When manure from storage is applied to land this is associated with use of diesel for land application, emissions of ammonia and nitrous oxide, and possible methane reductions if the treatment includes biogasification. Further, the land application serves as fertiliser inputs of N, P and K so that the input of mineral fertilisers to the field can be reduced. When mineral fertilisers are reduced this also implies reductions in ammonia and nitrous oxide emissions. The net emissions of ammonia and nitrous oxides are the difference between the induced emissions related to the application of the manure and the avoided emissions related to the displaced mineral fertiliser.

The abovementioned way of modelling manure treatment implies that all fertiliser (mineral and manure) in the plant cultivation system needs to be modelled as mineral fertiliser. If not, the credit (i.e. avoided mineral fertiliser) of utilising manure as fertiliser would be double counted. This way of modelling is implemented in the ISO 14040/44 switch mode. However, since this way of modelling is most often not used in attributional modelling, the credits for the use of manure as fertiliser have been moved to the crop cultivation system for the switch modes for average/allocation, PAS2050 and IDF.

Table 6.6: Overview of the modelling of affected exchanges related to manure in the four included switch modes.

Item related to manure	ISO 14040/44	Average/allocation	PAS2050	IDF
Emissions from manure N when applied to land	Animal (manure treatment) Excluded from crop	Crop cultivation Excluded from manure treatment	Crop cultivation Excluded from manure treatment	Crop cultivation Excluded from manure treatment
Avoided emissions induced by manure when substituting mineral fertiliser	Animal (manure treatment) Excluded from crop	Crop cultivation Excluded from manure treatment	Crop cultivation Excluded from manure treatment	Crop cultivation Excluded from manure treatment
Credits from avoided mineral fertiliser-production	Animal (manure treatment) Excluded from crop	Crop cultivation Excluded from manure treatment	Crop cultivation Excluded from manure treatment	Crop cultivation Excluded from manure treatment
Manure treatment process; diesel for land application etc.	Animal (manure treatment) Excluded from crop	Animal (manure treatment) Excluded from crop	Animal (manure treatment) Excluded from crop	Animal (manure treatment) Excluded from crop

In the ISO14040/44 (consequential) switch, when crops are using manure N, the production of this N-fertiliser is modeled as mineral fertiliser. Efficiency of manure N relative to mineral fertiliser N is taken into account

In the other switch modes (average/allocation, PAS2050, and IDF), when crops are using manure N, the production of this N-fertiliser is modeled as an allocated share of the dairy cow system.

In PAS2050 and IDF, when crops are using manure N, the manufacture of this N-fertiliser is modeled as in the average/allocation switch mode, but here the allocated share is 0%. This is based on the interpretation of Dairy UK et al. (2010, p 9) and IDF (2010, p 20).

The emissions of ammonia and nitrous oxide related to the application of 1 kg N as mineral fertiliser, manure and urine/dung deposited on grass is calculated as described in **chapter 7.4**; **Equation 7.3** and **Equation 7.5**.

6.7 System boundaries, point of allocation and switches

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 6.3** to **Figure 6.5** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

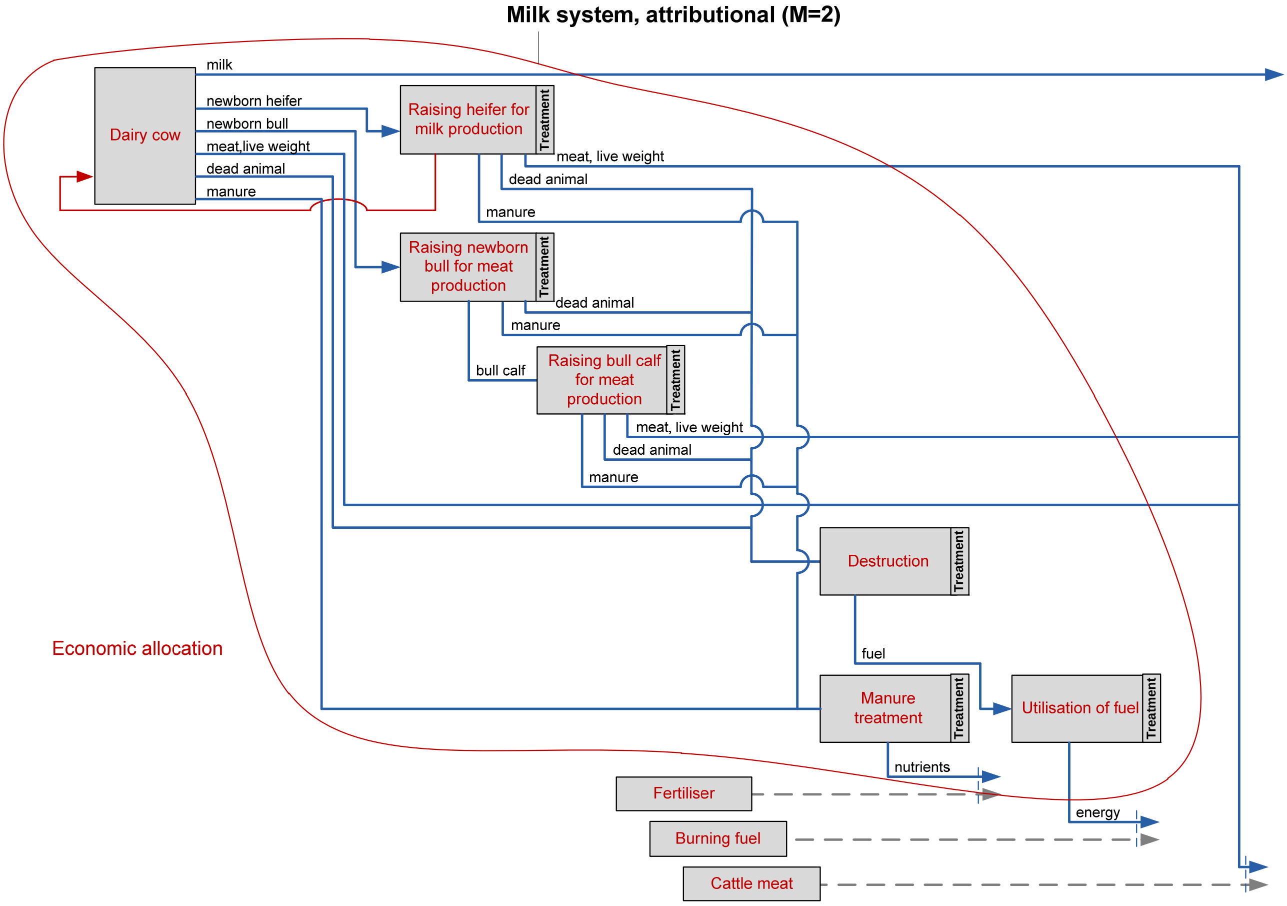
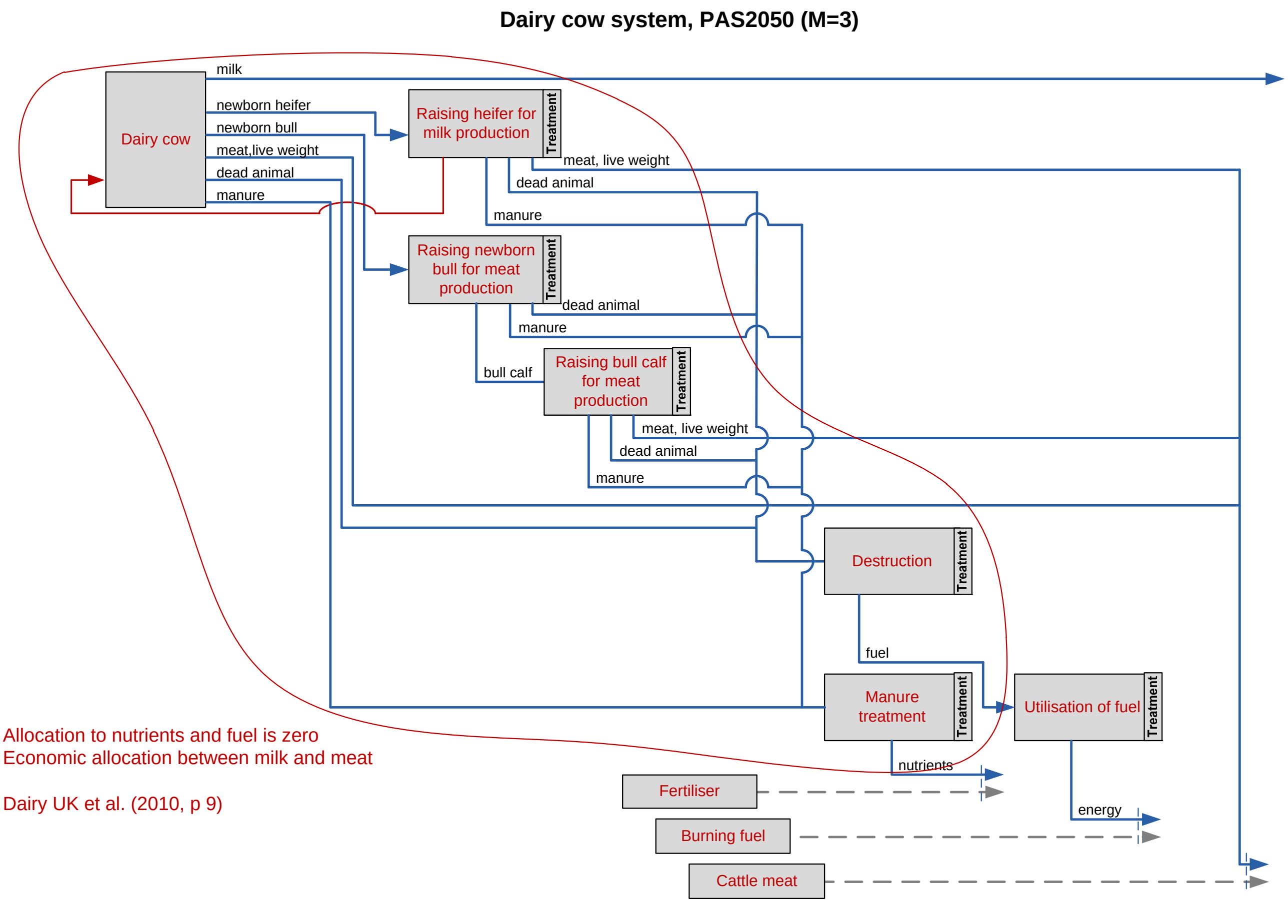


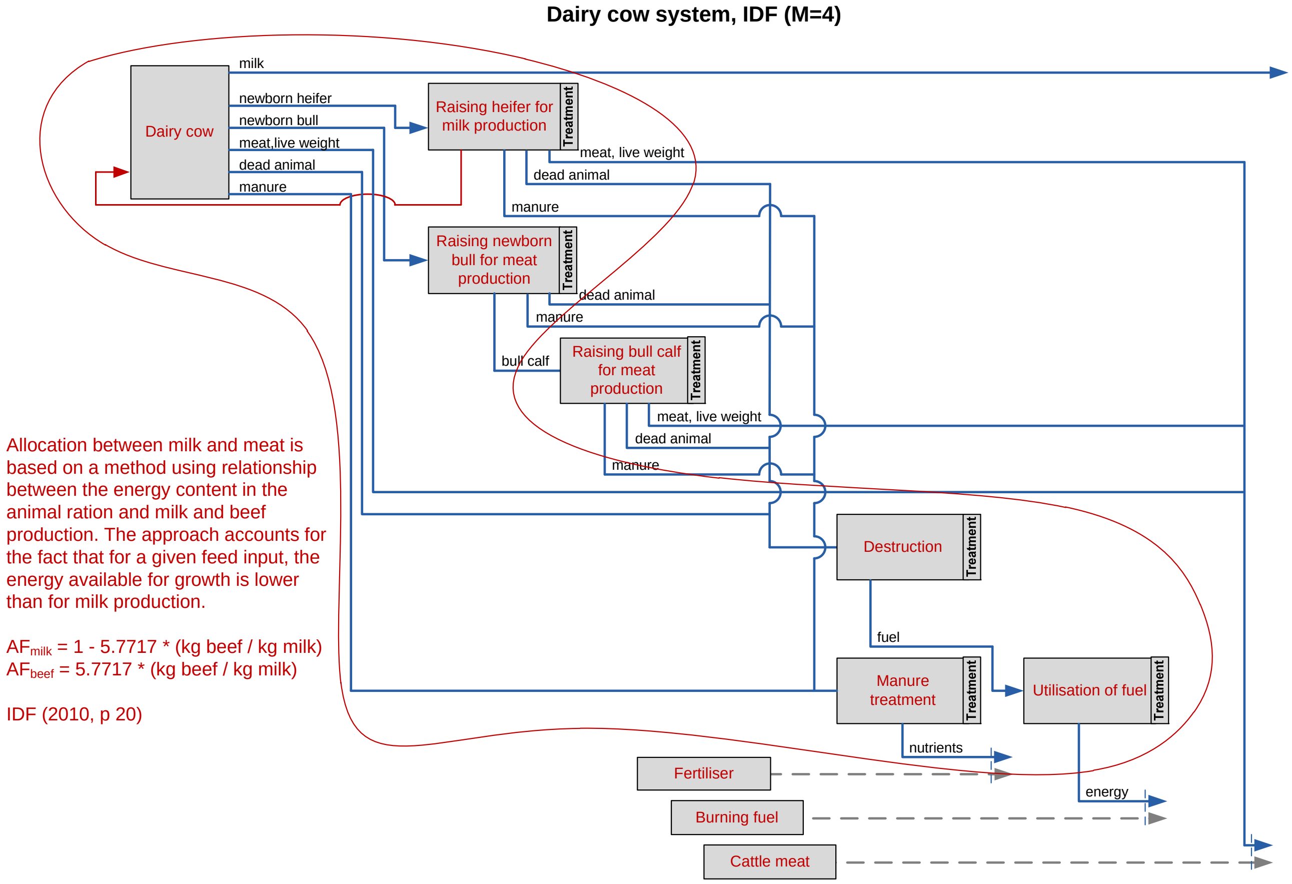
Figure 6.3: Milk system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.



Allocation to nutrients and fuel is zero
Economic allocation between milk and meat

Dairy UK et al. (2010, p 9)

Figure 6.4: Milk system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.



Dairy cow system, IDF (M=4)

Allocation between milk and meat is based on a method using relationship between the energy content in the animal ration and milk and beef production. The approach accounts for the fact that for a given feed input, the energy available for growth is lower than for milk production.

AF_{milk} = 1 - 5.7717 * (kg beef / kg milk)
AF_{beef} = 5.7717 * (kg beef / kg milk)

IDF (2010, p 20)

Figure 6.5: Milk system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

6.8 Special modelling for farm specific life cycle inventory

Individual farms sometimes send small heifers to external raising and then receive the animals back when they are fully or partially grown up. In the model, external raising is modelled as national average of the country in which the external raising takes place. The amount of external raising (in unit of live weight gain) demanded is calculated as in **Equation 6.25**.

Equation 6.25

$$\begin{gathered}\text{external weight gain} = \\ \text{no heads received from external raising x weight when received} \\ -\text{no heads sent to external raising x weight when sent}\end{gathered}$$

The reference flow of the ‘Raising heifer for milk production’ activity is in unit of number of calves (heads) sent to raising. In order to use the information in **Equation 6.25**, this can be converted to weight gain based on information in the input parameters in the activity.

When heifers are sent to external raising, the farm specific ‘Raising heifer for milk product’ must be adjusted to account for lower feed inputs and subsequent emissions and manure etc. This is done by reducing the feed requirement by a percentage which represent how much of the heifer’s total weight gain that is obtained externally. The percentage is calculated as the weight gain as of **Equation 6.25** divided by the total weight gain in the ‘Raising heifer for milk product’ activity (farm internal and external).

7 The plant cultivation system

The plant production activities supplies the main feedstock input to the bovine system. It is also the plant production activities that occupy the most land, i.e. these activities trigger the indirect land use change effects.

7.1 Overview of the plant cultivation system

The cultivation of grass (naturally grown or cultivated), ensilage and crops supplies almost all feed inputs to the cattle system, either directly when grass, ensilage or crops are used as feed or indirectly when the crops have been processed in the food industry before used as feed (oil meals, whey, molasses).

Within the grass, ensilage and crop cultivation system, the activities in **Table 7.1** are inventoried and accounted for separately in the model.

Table 7.1: Included activities in the plant cultivation system.

Activities within the plant cultivation system	**Description**
Activities	
Barley	These activities include the cultivation of annual crops. The product outputs are crops. Crop residues/straw is a by-product/waste which may have different destinations: it is left in the field or it is sent to utilisation for energy purposes in heat and power production
Wheat	
Oat	
Corn	
Soybean	
Rapeseed	
Sunflower	
Sugar beet	
Oil palm	This activity includes oil palm plantations. The oil palm is a perennial crop. The product output is fresh fruit bunches (FFB) which are sent to a palm oil mill. Crop residues are left in the plantation as mulch.
Permanent grass incl. grass ensilage	This activity includes naturally grown grass and cultivated permanent pasture. The product output is either fresh grass (direct grassing) and grass ensilage. There are no by-products from this activity. All supply of grass from this activity is fully consumed by animals in the agricultural sector of which bovines consumes near to 100% (minor amounts may be used by horses, sheep, goats etc.)
Rotation grass incl. grass ensilage	This activity includes cultivated pasture in rotation. The product output is either fresh grass (direct grassing) and grass ensilage. There are no by-products from this activity. All supply of grass from this activity is fully consumed by animals in the agricultural sector of which bovines consumes near to 100% (minor amounts may be used by horses, sheep, goats etc.)
Roughage, maize ensilage	This activity includes the cultivation of crops (not grass) for ensilage including grain crops (wheat, barley, oat, rye), maize, peas. The product output is ensilage. There are no by-products from this activity. All supply of grass from this activity is fully consumed by animals in the agricultural sector of which bovines consumes near to 100% (minor amounts may be used by horses, sheep, goats etc.)
Treatment activities	
Utilisation of crop residues for energy purposes	This activity is a treatment activity which includes transport of the straw to a combined heat and power plant and the burning of the crop residues. The reference product of the activity is treatment of crop residues. The energy output is a by-product that displaces electricity and heat.

The plant cultivation activities supplies crops or grass/ensilage as determining products. In addition to this, the treatment of plant residues supply by-products: electricity and district heating. The by-products supplied by the utilisation of straw for energy purposes are not described in this chapter, because these treatment activities are not part of the plant cultivation system. The activities are described in **section 9.4**.

7.2 Market delimitation of the products supplied by the cultivation system

The products in **Table 7.1** may be traded on common markets or on differentiated markets. This section considers the differentiation of the markets on which the products in the grass, ensilage and crop cultivation are traded.

Geographical delimitation

Plant material used as feed for the cattle system can either be produced locally on the farm, or it can be purchased on the market. The first applies to grass, grass ensilage, other ensilage and home grown grain crops, and the latter applies to grain crops purchased by the cattle farm and to crops that are processed in the food industry before used as feed, e.g. soybean meal, rapeseed meal, molasses etc. The geographical location of the home grown feedstuff is by definition the same as the cattle farm. The geographical location of the suppliers of non-farm specific grown feedstuff is not necessary in the same country/location as the milk system. In the following, the inventoried countries/regions for each included crop are specified, see overview in **Table 7.2**. Generally, the included countries are based on the following considerations:

- Most crops are produced in the countries of the milk system; Sweden and Denmark. Hence these locations are included
- Locations for crops that are not grown in the countries of the milk system are modelled as the major delivering country to the cattle system (or to the food industry before it is processed into feedstuff). This is relevant for corn (European average in included), sunflower (France is included), soybean (Brazil is included) and oil palm (Malaysia is included).
- Further, the global market for feed energy is considered (see **chapter 9.1**). This market involves the supply of barley to the global market. Obviously, the Danish and Swedish supply to the global market is of minor significance/relevance. Therefore, the suppliers to the global market for barley have also been identified. This identification leads to the inclusion of European average, Russia and Ukraine. The identification is further described below **Table 7.2**.

The included locations in the inventory for each crop are summarised in **Table 7.2**.

Table 7.2: Included locations in the inventory of crops in the plant cultivation system.

Activities within the plant cultivation system	farm	DK	SE	BR	RU	UA	FR	EU aver	MY
Barley	X	X	X		X	X		X	
Wheat	X	X	X						
Oat	X	X	X						
Corn								X	
Soybean				X					
Rapeseed		X	X						
Sunflower							X		
Sugar beet		X	X						
Oil palm									X
Permanent grass incl. grass ensilage	X	X	X	X					
Rotation grass incl. grass ensilage	X	X	X						
Roughage, maize ensilage	X	X	X						

Considering the global market for feed energy, barley is the cheapest source of energy feed; according the FAPRI (2012)[3], the prices of feed energy in 2006/07 from corn and wheat relative to barley were 1.10 and 1.32 respectively. Therefore, barley is regarded as the most competitive and thereby the most relevant source of energy feed to be considered when inventorying the global market for feed energy. The market for barley will be elaborated in the following. The global generic markets for energy feed and protein feed are described in **chapter 9.1**.

In 2005, the world production of barley was 139 million tonne (FAOSTAT 2012). In 2005, approximately 25 million tonne was traded (FAOSTAT 2012). Thus, a considerable share of the global production is not used in the country of origin. **Table 7.3** presents data on the producers which has grown at the largest rate (in absolute numbers) in different time periods.

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[3] The prices from FAPRI (2012) are in units USD/tonne. This has been converted to price per MJ net feed energy by use of dry matter content and feed energy content from Møller et al. (2005).

Table 7.3: Trend and production of barley. Figures are shown for the top-five countries with the highest trend for different periods. The figures are based on FAOSTAT (2012).

Country	Trend 1995-2000 (mill t yr-1)	Production 2000 (mill t)
Spain	0.65	11.1
France	0.29	9.7
Germany	0.11	12.1
Turkey	0.07	8.0
Ireland	0.04	1.3

Country	Trend 2000-2005 (mill t yr-1)	Production 2005 (mill t)
Australia	0.53	9.5
Turkey	0.34	9.5
Ukraine	0.28	9.0
Morocco	0.26	1.1
Iran (Islamic Republic of)	0.21	2.9

Country	Trend 2005-2010 (mill t yr-1)	Production 2010 (mill t)
Spain	0.42	8.2
Morocco	0.33	2.6
Argentina	0.33	3.0
France	0.26	10.1
Ukraine	0.16	8.5

Country	Trend 1995-2010 (mill t yr-1)	Production 2010 (mill t)
Ukraine	0.24	8.5
France	0.15	10.1
Australia	0.11	7.3
Argentina	0.11	3.0
Russian Federation	0.07	8.4

It appears from the different figures in **Table 7.3**, that the identification of the margin supplier of barley is highly influenced by the period for which the trend is calculated. It is assumed that Ukraine which has the largest trend in 1995-2010 is a good representative of the marginal producer of barley to the global market.

It is evident that this identification is related to significant uncertainties. However, it should be noticed that the global market for barley is not widely affected in the model; it is only affected in cases where the generic global market for feed energy is affected, and this is only the case when either constrained feedstuff is used (e.g. when rapeseed meal is used; rapeseed meal is constrained by the demand for rapeseed oil) or when the used feedstuff is associated with the production of by-products of feed energy. Further, it should be noticed, that the global market for barley is not considered in the switch modes for average/allocation, PAS2050 and IDF.

Temporal delimitation

The inventory of Danish and Swedish baselines is for year 2005. So for all other locations than ‘farm’ in **Table 7.2**the inventory is aimed at representing 2005. For ‘farm’ the year of inventory is whatever parameter values are entered in the model.

7.3 Inventory of inputs to the plant cultivation system

Definition of products, material to treatment, and exchanges with the environment to be inventoried

The plant cultivation system uses different products. The product inputs are inventoried for all activities in **Table 7.1**. The uses of the following types of inputs are specifically inventoried:

1. Fertiliser, N
2. Fertiliser, P
3. Fertiliser, K
4. Pesticides
5. Energy use for traction
6. Energy use for drying crops
7. Transport of materials
8. Land tenure (occupation of land), this is what causes indirect land use changes

Other product inputs, i.e. inputs of capital goods and services are obtained by use of generic databases.

7.4 Inventory of N related field emissions

A field-emission-model is established in order to enable calculating the emissions relating to the carbon and nutrient cycles (N and P) from one hectare of crops. The relevant emissions include N_2O, NH_3, NO_X and NO_3. 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. In the following, the methodology of the modelling of each emission is described.

Nitrogen emissions:

On basis of the inputs (e.g. synthetic fertiliser) to the field and outputs (e.g. harvested crop) from the field, the surplus of N is calculated:

Equation 7.1

$$N_{surplus} = N_{input} - N_{output}$$

The surplus of N is lost to the environment through different environmental pathways. The losses of N_2O, NH_3, NO_X, NO_3^- and N_2 are quantified and subtracted from the N-surplus. The residual is assumed equal to N_2.

Equation 7.2

$$N_{surplus} = NH_3\text{-}N + NO_x\text{-}N + N_20\text{-}N \text{ (direct)} + N_2 + NO_3\text{-}N$$
$$N_2 = N_{surplus} - (NH_3\text{-}N + NO_x\text{-}N + N_20\text{-}N \text{ (direct)} + NO_3\text{-}N)$$

N_2O-N (direct)

The emissions of N_2O are divided into direct and indirect emissions for which each type is specifically inventoried. The method used for the calculation of N_2O emissions is the method described in IPCC (2006, chapter 11). This method is applicable to annual crops, perennial crops, grassland and managed forests. When the method is used for perennials, it is required to take into account intermediate flows, i.e. storage of substances in plant material growth and release of decomposed plant material from previous year's growth. However, this is not relevant for the crops and grassland inventoried in the present study.

According to IPCC (2006, p 11.7), direct N_2O-N can be calculated as:

Equation 7.3

$$\mathrm{N_2O\text{-}N_{Direct}} = \left(\mathrm{N_2O\text{-}N_{N\,inputs}}\right) + \left(\mathrm{N_2O\text{-}N_{OS}}\right) + \left(\mathrm{N_2O\text{-}N_{PRP}}\right)$$

Where:

$$\mathrm{N_2O\text{-}N_{N\,inputs}} = (\mathrm{F_{SN}} + \mathrm{F_{ON}} + \mathrm{F_{CR}} + \mathrm{F_{SOM}}) \cdot \mathrm{EF_1}$$
$$\mathrm{N_2O\text{-}N_{OS}} = \mathrm{F_{OS}} \cdot \mathrm{EF_{2CG}}$$
$$\mathrm{N_2O\text{-}N_{PRP}} = \mathrm{F_{PRP}} \cdot \mathrm{EF_{3PRP}}$$

Where:

N_2O-N_{Direct} = annual direct N_2O–N emissions produced from managed soils, kg N_2O–N yr^{-1}

N_2O-$N_{N\ inputs}$ = annual direct N_2O–N emissions from N inputs to managed soils, kg N_2O–N yr^{-1}

N_2O-N_{OS} = annual direct N_2O–N emissions from managed organic soils, kg N_2O–N yr^{-1}

N_2O-N_{PRP} = annual direct N_2O–N emissions from urine and dung inputs to grazed soils, kg N_2O–N yr^{-1}

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}

F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, kg N yr^{-1}

F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr^{-1}

If specific calculations or data are not available, then this parameter is calculated from (IPCC 2006, equation 11.7A and Table 11.2):

Equation 7.4

$$F_{cr} = [\mathrm{Crop} \cdot \mathrm{Slope} + \mathrm{Intercept}] \cdot [\ N_{AG} \cdot (1\text{-}\ \mathrm{FRAC_{Remove}}) + (R_{BG\text{-}BIO} \cdot N_{BG})\ ]$$

where:

Crop · **Slope** + **Intercept** = **AG_{DM}** = Aboveground residue dry matter (Mg/ha). Crop is the dry matter yield, 1000 kg/ha yr, and slope and intercept are constants which are obtained from IPCC (2006, Table 11.2)

N_{AG} = N content of above ground residues for crop, kg N $(kg\ dm)^{-1}$. Data obtained from IPCC (2006, Table 11.2)

$Frac_{Remove}$ = Fraction of above ground residues of crop removed annually for purposes such as feed, bedding and construction, kg N $(kg\ crop\text{-}N)^{-1}$. If no data assume no removal

$R_{BG\text{-}BIO}$ = Ratio of below-ground residues to above-ground residues[4], kg dm $(kg\ dm)^{-1}$. Data obtained from IPCC (2006, Table 11.2)

N_{BG} = N content of below ground residues for crop, kg N $(kg\ dm)^{-1}$. Data obtained from IPCC (2006, Table 11.2)

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1}

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[4] Notice that $R_{BG\text{-}BIO}$ in IPCC (2006, table 11.2) is defined as "Ratio of below-ground residues to above-ground biomass". This cannot be correct since IPCC (2006, equation 11.7A) would then calculate N in above-ground residues + N in more than below-ground residues, i.e. more than 100% of N in crop residues.

This parameter 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.

F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1} (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

This parameter is linked to the cattle system, i.e. there is established a relation between the farmers land (and thereby crops) and the amount of urine/dung deposited by grazing animals.

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$

Data for this parameter are obtained from IPCC (2006, table 11.1)

EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha^{-1} yr^{-1} (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

Data for this parameter are obtained from IPCC (2006, table 11.1)

EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O–N (kg N input)$^{-1}$ (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

Data for this parameter are obtained from IPCC (2006, table 11.1)

N_2O-N (indirect)

N_20-N (indirect) is calculated from the N volatilised and leached from the field. According to IPCC (2006, equation 11.9 and 11.10), the indirect N_2O-N can be calculated as:

Equation 7.5

$$\begin{aligned}\mathrm{N_2O\text{-}N_{Indirect}} = {} & [(\mathrm{F_{SN}} \cdot \mathrm{Frac_{GASF}}) + (\mathrm{F_{ON}} + \mathrm{F_{PRP}}) \cdot \mathrm{Frac_{GASM}}] \cdot \mathrm{EF_4} \\ & + (\mathrm{F_{SN}} + \mathrm{F_{ON}} + \mathrm{F_{PRP}} + \mathrm{F_{CR}} + \mathrm{F_{SOM}}) \cdot \mathrm{Frac_{LEACH}} \cdot \mathrm{EF_5}\end{aligned}$$

where:

the first row relates to annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils, kg N_2O–N yr^{-1}

the second row refers to annual amount of N_2O–N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O–N yr^{-1}

$Frag_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied)$^{-1}$

Data for this parameter are obtained from IPCC (2006, table 11.3)

$Frag_{GASM}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied or deposited)$^{-1}$

Data for this parameter are obtained from IPCC (2006, table 11.3)

$Frag_{LEACH}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$

Data for this parameter are obtained from IPCC (2006, table 11.3)

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N_2O (kg NH_3–N + NO_x–N volatilised)$^{-1}$]

Data for this parameter are obtained from IPCC (2006, table 11.3)

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)$^{-1}$

Data for this parameter are obtained from IPCC (2006, table 11.3)

The remaining parameters in **Equation 7.5** are described under **Equation 7.3**.

NH_3-N and NO_x-N:

The sum of nitrogen in ammonia and nitrogen oxides (NH_3-N + NO_X-N) is calculated according to IPCC (2006, chapter 11), based on $Frag_{GASF}$ and $Frag_{GASM}$ which specify the proportion of the N in synthetic fertiliser and organic fertiliser respectively that is volatilised as ammonia and NO_X (see first row of **Equation 7.5**). The emissions of the two substances are determined using a generalised relationship between NH_3 and NO_X. This relationship is obtained from FAO and IFA (2001) which estimates the global sources of NH_3, NO_X and N_2O in 1995. Based on the global figures provided in FAO and IFA (2001, table 10 and 13) on emissions of NH_3-N and NO-N from fertilised cultivation of crops it can be estimated that the sum (NH_3-N + NO-N) is distributed on NH_3-N and NO_X-N as 88% and 12% respectively. It is assumed the share of NO_2 in NO_x is negligible.

NO_3-N:

NO_3-N is calculated according to IPCC (2006, chapter 11), based on $Frag_{LEACH}$ which specifies the proportion of the N added to soils that is lost through leaching and runoff (see second row of **Equation 7.5**).

7.5 Inventory of CO_2 from managed drained organic soils

CO_2 emissions from managed drained organic soils are quantified using the default emission factors in IPCC (2006, p 5.19). For all crops in the included regions (except soybean in Brazil and oil palm in Malaysia) the default emission factor for cold temperate climate regimes is 5.0 t C ha^{-1} yr^{-1} which corresponds to 18.3 t CO_2 ha^{-1} yr^{-1}. The emission factor for oil palm is special because oil palm is a perennial crop that can be characterised as something between an annual crop and a managed forest. This category is not covered by IPCC (2006). The emission factor for oil palm cultivated on peat is 27.5 t CO_2 ha^{-1} yr^{-1} (Schmidt 2011).

8 The food industry system

Generally, the food industry produces food, but a significant share of the outputs from the food industry is used as animal feed; soybean meal, rapeseed meal, molasses, beet pulp, wheat bran etc. This section describes the relevant food industries that produce feedstuff as listed in **section 6.3**.

It should be noticed that the inventory of the food system is generally based on literature data. Therefore, the description of the methodology for inventory is not as comprehensive for these activities as for the activities in the cattle plant cultivation systems. The major methodological issue is to frame the different food industries in compliance with the inventory framework as of **chapter 3**.

8.1 Overview of the food industry system

Many food industries produce feed, either as the reference product or as a by-product. The latter is the main case, but there are also industries within the food industry produce feed as the reference output, i.e. soybean meal. Also palm oil is used as a feedstuff. Within the food industry, the activities in **Table 8.1** and **Table 8.2** are inventoried and accounted for separately in the model. The feedstuff relevant for the cattle system is indicated in brackets in the first column in **Table 8.1** and **Table 8.2**.

Table 8.1: Included activities in the food industry system related to vegetable oils and oil meas. The product-outputs from the activities which are used as feed in the cattle system are indicated in brackets.

Inventoried activities	Description
Soybean meal system	
Soybean oil mill [soybean meal, SBM]	This activity includes the crushing of soybeans. The reference output is soybean meal. Crude soybean oil is a material for treatment; the soybean oil cannot displace other oils before refining; therefore the refining of soybean oil becomes a treatment activity; see activity 'Soybean oil refinery'. (Dalgaard et al. 2007)
Soybean oil refinery	Treatment activity. The reference product is the treatment (refining) of the crude soybean oil, the refined soybean oil is a by-product, and free fatty acids (FFA) is a material for treatment; see activity 'Utilisation of FFA as feed'. (Schmidt 2010b)
Rapeseed oil system	
Rapeseed oil mill [rapeseed meal, RSM]	This activity includes the crushing of rapeseed. The reference output is crude rapeseed oil. Rapeseed meal is a material for treatment; see activity 'Utilisation of RSM as feed'. (Schmidt 2010b)
Rapeseed oil refinery [NBD rapeseed oil]	This activity includes refining of crude rapeseed oil. The reference product is refined rapeseed oil. Free fatty acids is a material for treatment; see activity 'Utilisation of FFA as feed'. (Schmidt 2010b)
Utilisation of RSM as feed [Feed energy] [Feed protein]	Treatment activity. The reference product is the treatment (utilisation) of RSM as feed, and the feed energy and protein are by-products. The activity is included because the utilisation of RSM is needed before it can substitute feed energy and protein. (Schmidt 2010b)
Sunflower oil system	
Sunflower oil mill [sunflower meal, SFM]	This activity includes the crushing of sunflower. The reference output is crude sunflower oil. Sunflower meal (SFM) is a material for treatment; see activity 'Utilisation of SFM as feed'. (Schmidt 2007; 2010)
Utilisation of SFM as feed [Feed energy] [Feed protein]	Treatment activity. The reference product is the treatment (utilisation) of SFM as feed, and the feed energy and protein are by-products. The activity is included because the utilisation of SFM is needed before it can substitute feed energy and protein. (Schmidt 2007; 2010)
Palm oil system	
Palm oil mill	This activity includes the crushing of fresh fruit bunches (FFB). The reference output is crude palm oil. Electricity is a by-product. Kernels, empty fruit bunches (EFB), and effluent (POME) are materials for treatment; see activities 'Palm kernel oil mill', 'Utilisation of EFB as fertiliser' and 'Utilisation of POME as fertiliser'. (Schmidt 2010b)
Palm kernel oil mill [Palm kernel meal, PKM]	Treatment activity. The reference product is the treatment (crushing) of the kernels, the palm kernel meal (PKM) is a by-product, and crude palm kernel oil (CPKO) is a material for treatment; see activity 'Palm kernel oil refinery'. (Schmidt 2010b)
Palm oil refinery [NBD palm oil]	This activity includes refining of crude palm oil. The reference product is refined palm oil. Free fatty acids is a material for treatment; see activity 'Utilisation of FFA as feed'. (Schmidt 2010b)
Palm kernel oil refinery	Treatment activity. The reference product is the treatment (refining) of the crude palm kernel oil, the refined palm kernel oil is a by-product, and free fatty acids (FFA) is a material for treatment; see activity 'Utilisation of FFA as feed'. (Schmidt 2010b)
Utilisation of EFB and POME as fertiliser [N-fertiliser] [P-fertiliser] [K-fertiliser]	Treatment activity. The reference product is the treatment (utilisation) of EFB and POME as fertiliser respectively, and N-, P-, and K-fertilisers are by-products. The activity is included because the utilisation of EFB and POME are needed before it can substitute fertilisers. (Schmidt 2010b)
General for FFA from refineries	
Utilisation of FFA as feed [Feed energy] [Feed protein]	Treatment activity. The reference product is the treatment (utilisation) of FFA as feed, and the feed energy and protein are by-products. The activity is included because the utilisation of FFA is needed before it can substitute feed energy and protein. (Schmidt 2010b)

Table 8.2: Included activities in the food industry system related to sugar and flour production. The product-outputs from the activities which are used as feed in the cattle system are indicated in brackets.

Inventoried activities	Description
Sugar system	
Sugar mill [molasses] [beet pulp]	This activity includes the processing of sugar beets. The reference output is sugar. Molasses and beet pulp are materials for treatment; see activities 'Utilisation of molasses as feed' and 'Utilisation of beet pulp as feed'. (Nielsen et al. 2005)
Utilisation of molasses and beet pulp as feed [Feed energy] [Feed protein]	Treatment activities. The reference products are the treatment (utilisation) of molasses and beet pulp as feed respectively, and the feed energy and protein are by-products. The activities are included because the utilisation of molasses and beet pulp are needed before it can substitute feed energy and protein. (Nielsen et al. 2005)
Wheat flour system	
Wheat flour mill [wheat bran]	This activity includes the milling of wheat. The reference output is wheat flour. Wheat bran is a material for treatment; see activity 'Utilisation of wheat bran as feed'. (Nielsen et al. 2005)
Utilisation of wheat bran as feed [Feed energy] [Feed protein]	Treatment activity. The reference product is the treatment (utilisation) of wheat bran as feed, and the feed energy and protein are by-products. The activity is included because the utilisation of wheat bran is needed before it can substitute feed energy and protein. (Nielsen et al. 2005)

8.2 Market delimitation of products supplied by the food industry

The feedstuff products in **Table 8.1** and **Table 8.2** are traded on markets. This section considers the differentiation of the markets on which the products in the feedstuff is traded.

Geographical delimitation

Generally all feedstuff from the crop processing system is purchased on the market. The geographical location of the suppliers of this feedstuff is not necessary in the same country/location as the milk system, e.g. when purchasing soybean meal on the market, the affected suppliers of soybean may be located in Brazil.

The included locations in the inventory for each feedstuff supplier in the crop processing system are summarised in **Table 8.3**. The included locations in Table 8.3 are chosen based on the likely affected suppliers. Rapeseed oil mills, sugar mills and flour mills are assumed to be Danish or Swedish. Sunflower oil mills are assumed to be located in France because France is the most significant sunflower manufacturer in Europe. Brazil and Malaysia are included for soybean oil mills and palm oil mills because these are the major suppliers to the global markets for soybean meal and palm oil. For palm oil mills Indonesia has become a larger producer than Malaysia during the recent years. However, based on Schmidt (2007) it is estimated that production in Malaysia and Indonesia is similar.

Table 8.3: Included locations in the inventory of activities in the food industry system.

Activities within the food industry system	DK	SE	BR	FR	MY	GLO / unspec.
Soybean oil mill			X			
Soybean oil refinery			X			
Rapeseed oil mill	X	X				
Utilisation of RSM as feed						X
Sunflower oil mill				X		
Utilisation of SFM as feed						X
Palm oil mill					X	
Palm kernel oil mill					X	
Palm oil refinery					X	
Palm kernel oil refinery					X	
Utilisation of EFB and POME as fertiliser						X
Utilisation of FFA as feed						X
Sugar mill	X	X				
Utilisation of molasses and beet pulp as feed						X
Wheat flour mill	X	X				
Utilisation of wheat bran as feed						X

8.3 Inventory of soybean meal system (soybean meal)

This section presents an overview of the soybean meal system. The system is defined from the soybean oil mill and downstream for by-products and materials for treatment till the point of substitution.

In the Arla model soybean meal (SBM) is used as a feedstuff. The other parts of the system are included because this is joint production with the meal.

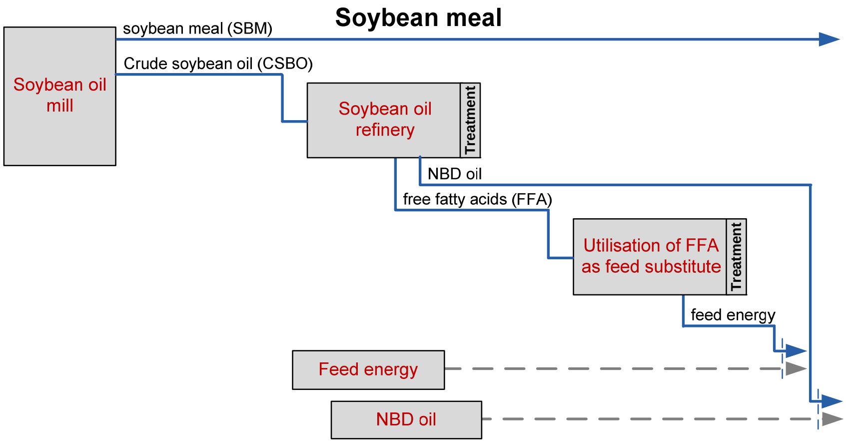

Figure 8.1: Overview of the transactions within the production system of soybean meal and downstream for by-products and materials for treatment until the point of substitution. Based on Dalgaard et al. (2008) and Schmidt (2010b).

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 8.2** to **Figure 8.4** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

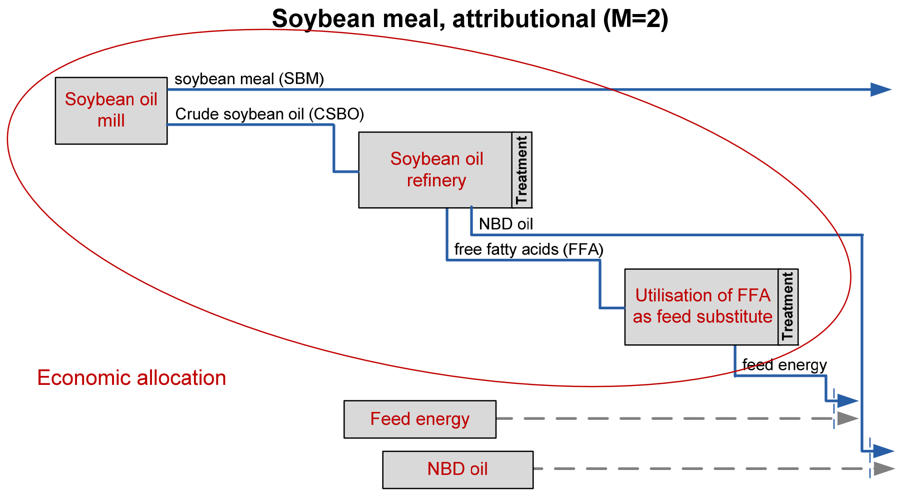

Figure 8.2: Soybean meal system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

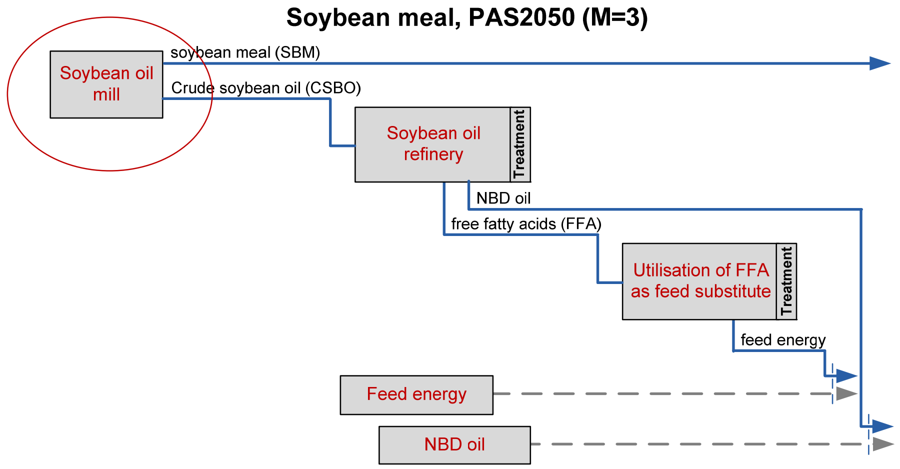

Figure 8.3: Soybean meal system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

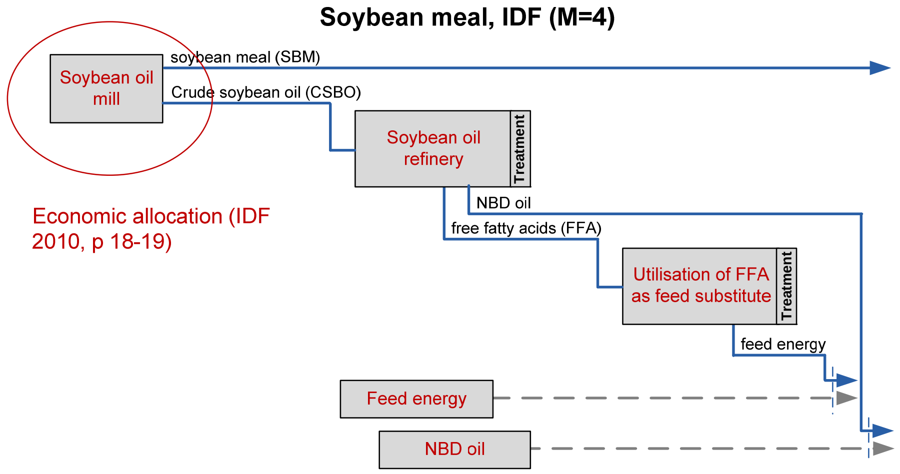

Figure 8.4: Soybean meal system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

8.4 Inventory of rapeseed oil system (rapeseed meal)

This section presents an overview of the crude rapeseed oil system. The system is defined from the rapeseed oil mill and downstream for by-products and materials for treatment till the point of substitution.

In the Arla model rapeseed meal (RSM) is used as a feedstuff. The other parts of the system are included because this is joint production with the meal.

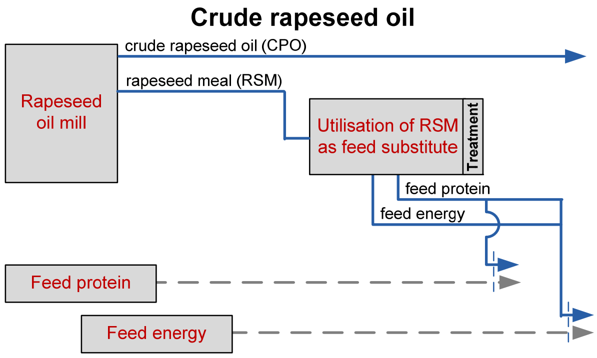

Figure 8.5: Overview of the transactions within the production system of crude rapeseed oil and downstream for by-products and materials for treatment until the point of substitution. Based on Schmidt (2010b).

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 8.6** to **Figure 8.8** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

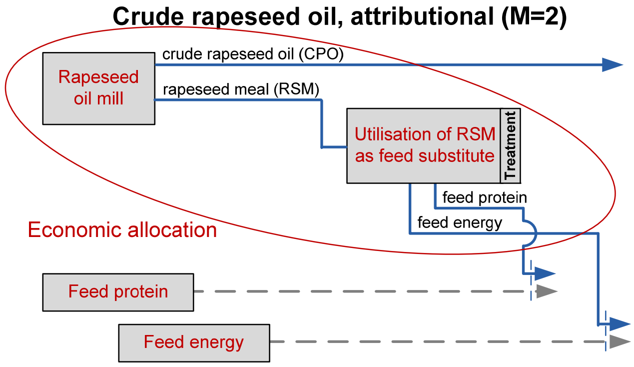

Figure 8.6: Rapeseed oil system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

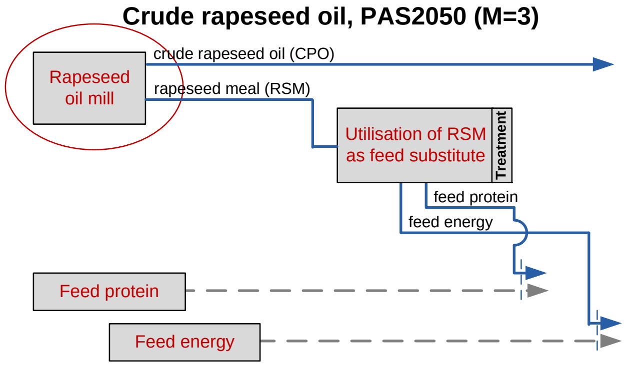

Figure 8.7: Rapeseed oil system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

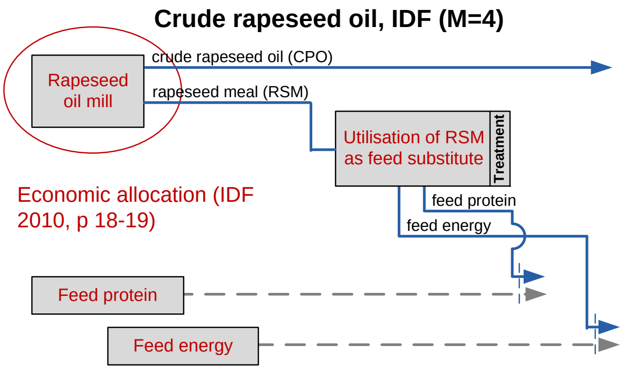

Figure 8.8: Rapeseed oil system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

8.5 Inventory of sunflower oil system (sunflower meal)

This section presents an overview of the crude sunflower oil system. The system is defined from the sunflower oil mill and downstream for by-products and materials for treatment till the point of substitution.

In the Arla model sunflower meal (SFM) is used as a feedstuff. The other parts of the system are included because this is joint production with the meal.

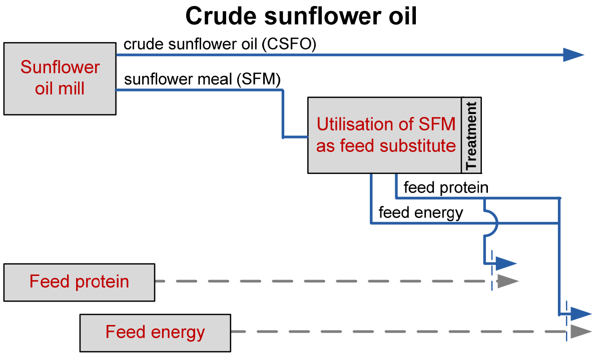

Figure 8.9: Overview of the transactions within the production system of crude sunflower oil and downstream for by-products and materials for treatment until the point of substitution. Based on (Schmidt 2007; 2010)

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 8.10** to **Figure 8.12** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

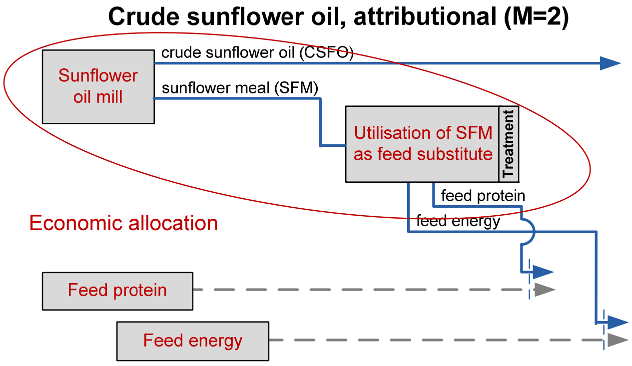

Figure 8.10: Sunflower oil system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

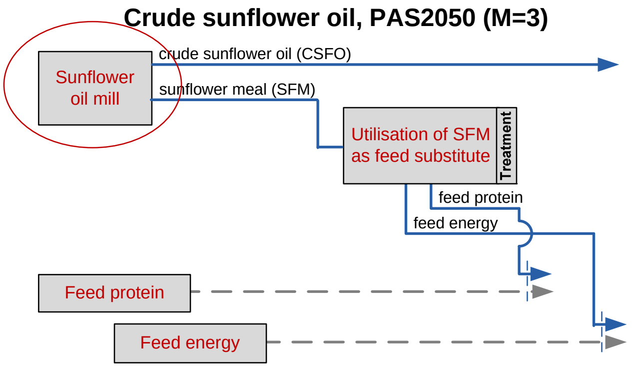

Figure 8.11: Sunflower oil system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

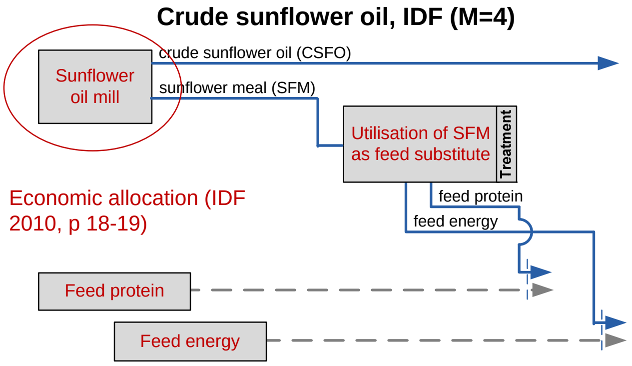

Figure 8.12: Sunflower oil system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

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

This section presents an overview of the palm oil system. The system includes two sub-systems:

- the palm oil mill, the palm kernel oil mill, the palm kernel oil refinery, and a number of treatment processes where the utilisation of materials for treatment is accounted for
- the palm oil refinery

The palm oil refinery is accounted for in a separate sub-system because this is not joint production with the system where the palm oil mill is. The refinery of the palm kernel oil is regarded as joint production with the palm oil mill because the material for treatment; kernels, links the palm oil mill with the palm kernel oil mill and refinery.

In the Arla model refined palm oil (NBD oil) and palm kernel meal (PKM) are used as a feedstuff. The other parts of the system are included because this is joint production with the NBD oil and the meal.

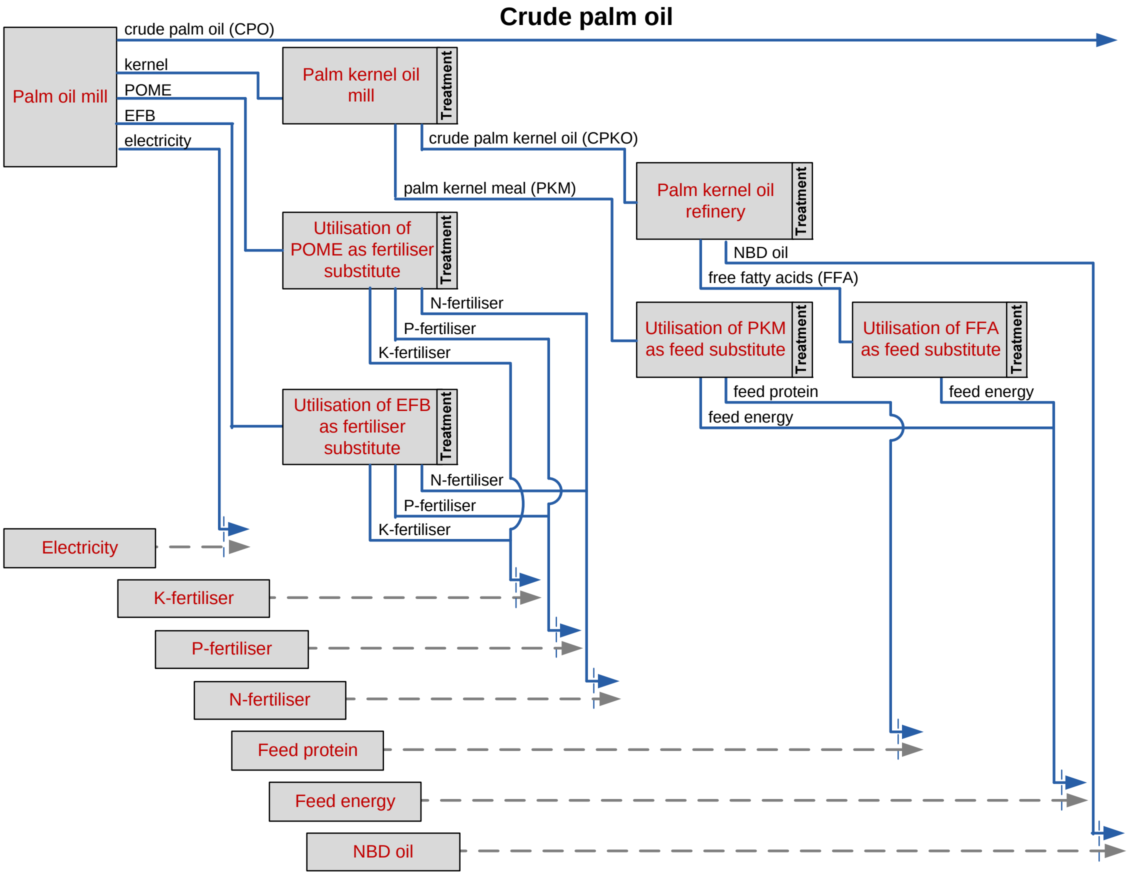

Figure 8.13: Overview of the transactions within the production system of crude palm oil and downstream for by-products and materials for treatment until the point of substitution. Based on Schmidt (2010b).

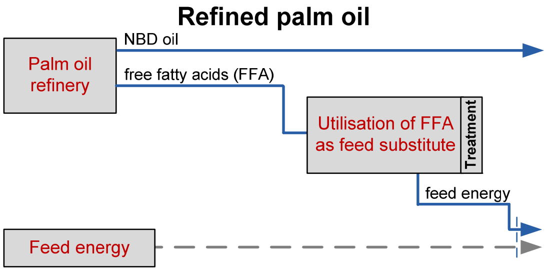

Figure 8.14: Overview of the transactions within the production system of refined palm oil and downstream for by-products and materials for treatment until the point of substitution. Based on Schmidt (2010b).

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 8.15** to **Figure 8.20** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

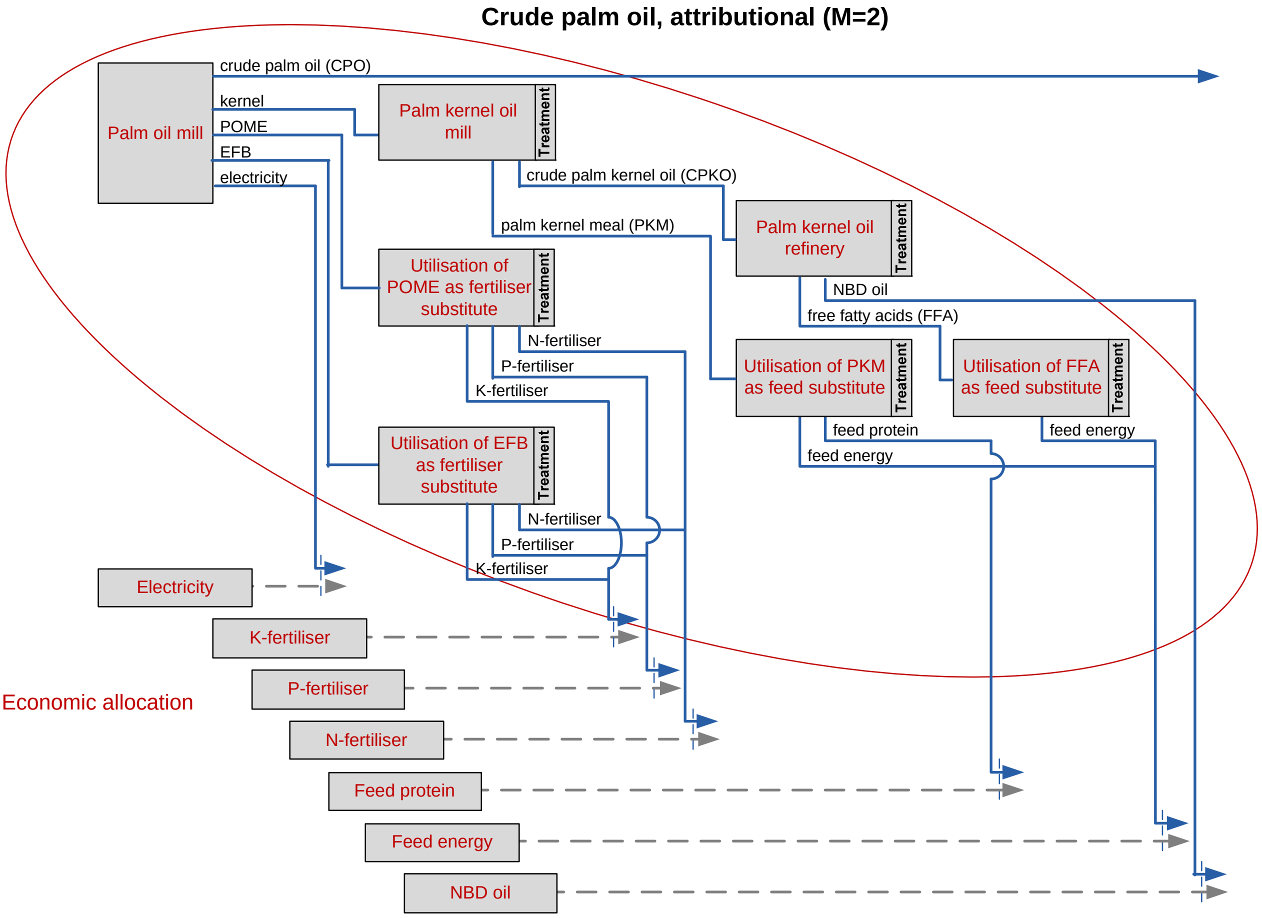

Figure 8.15: Crude palm oil system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

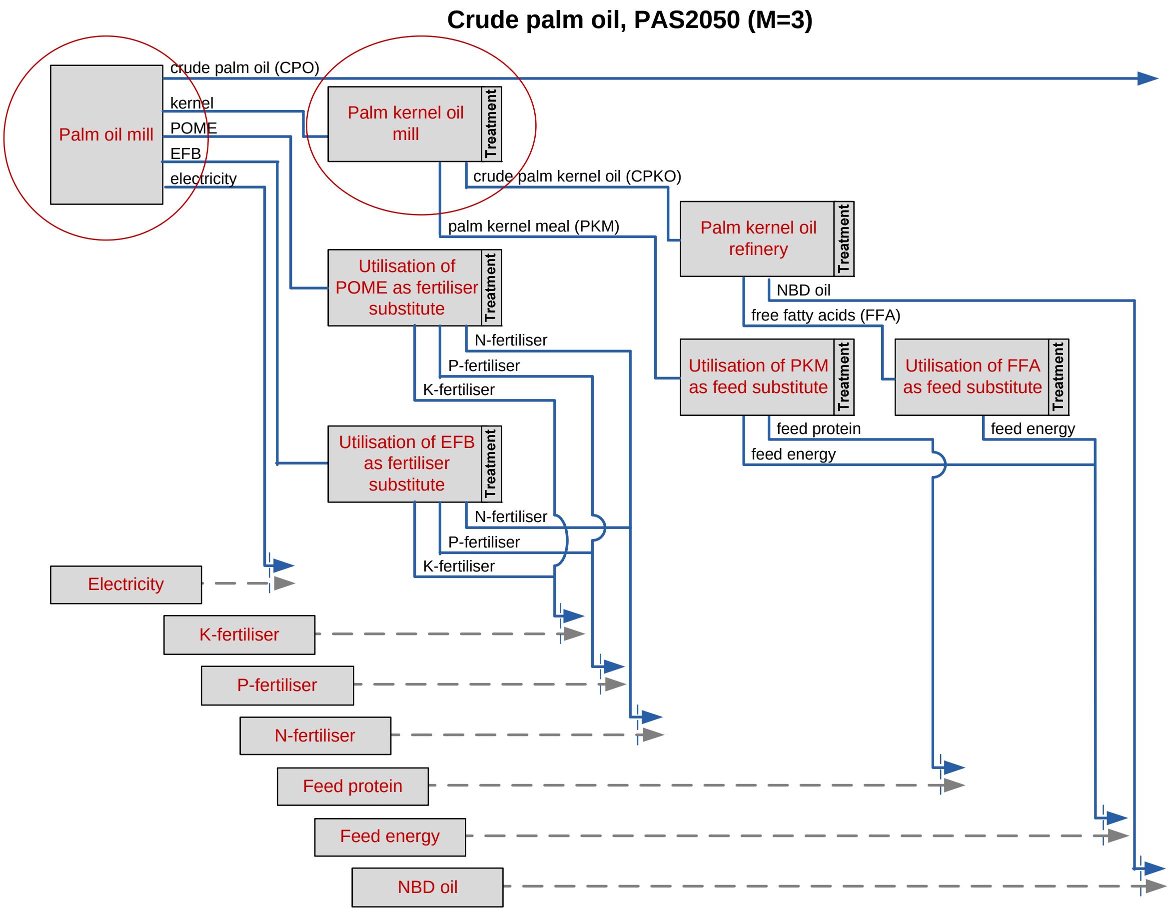

Figure 8.16: Crude palm oil system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

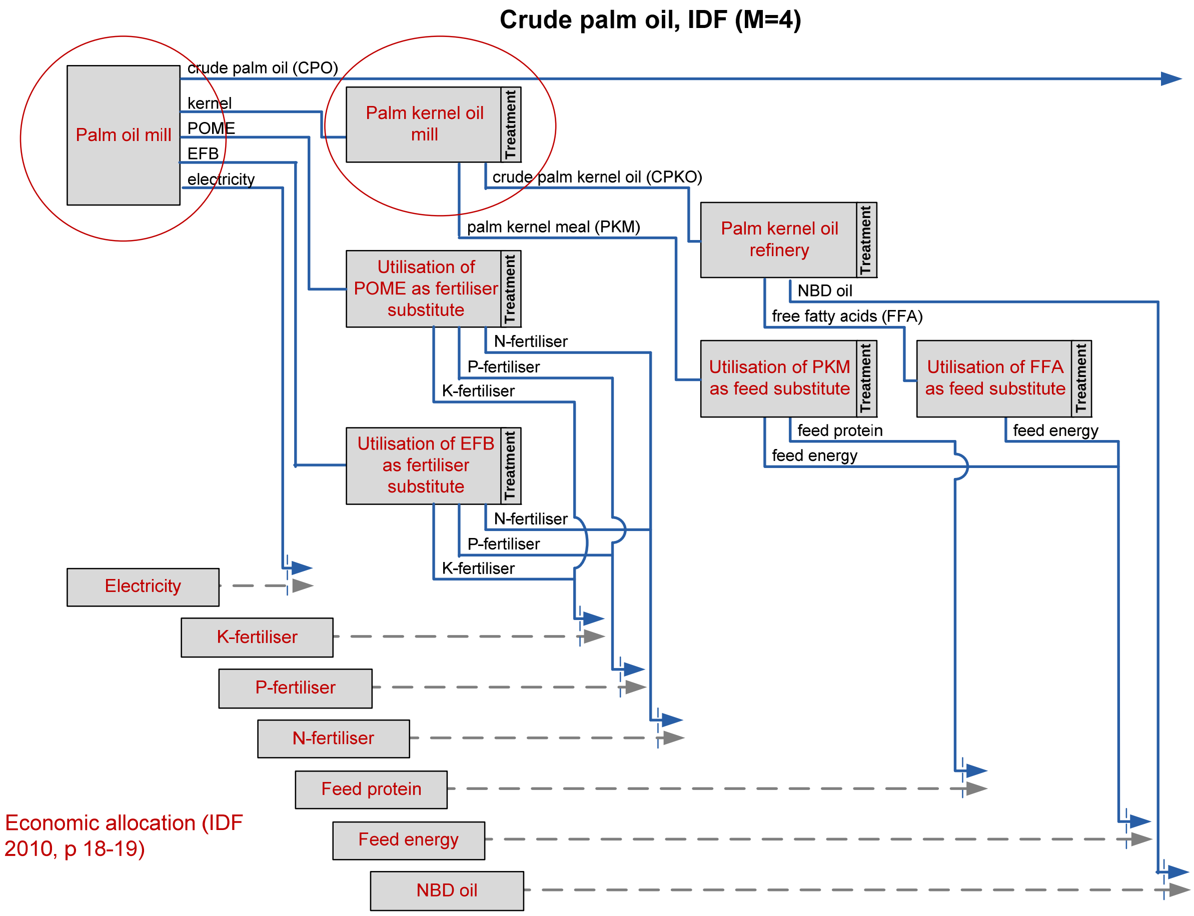

Figure 8.17: Crude palm oil system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

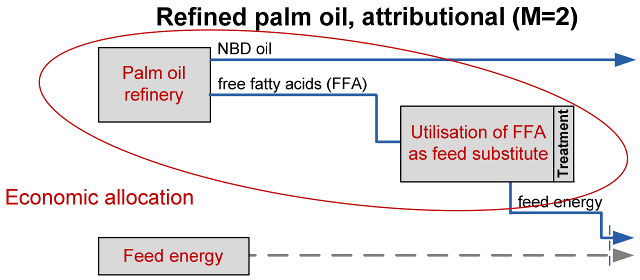

Figure 8.18: Palm oil refinery system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

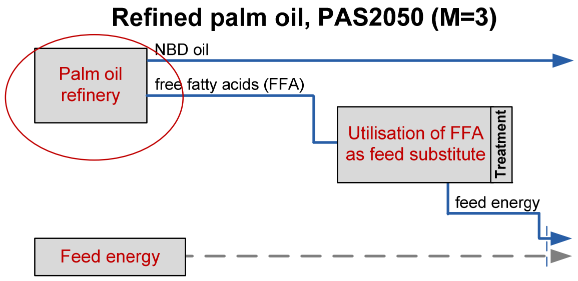

Figure 8.19: Palm oil refinery system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

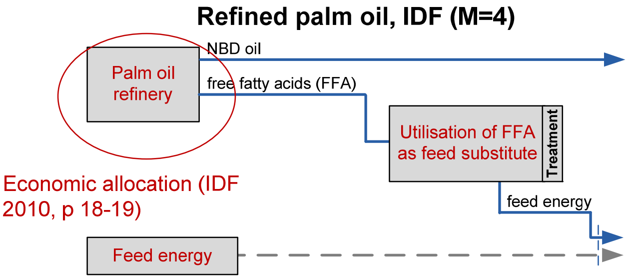

Figure 8.20: Palm oil refinery system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

8.7 Inventory of sugar system (molasses and beet pulp)

This section presents an overview of the sugar system. The system is defined from the sugar mill and downstream for by-products and materials for treatment till the point of substitution.

In the Arla model beet pulp and molasses are used as cattle feedstuff. The other parts of the system are included because this is joint production with these by-products.

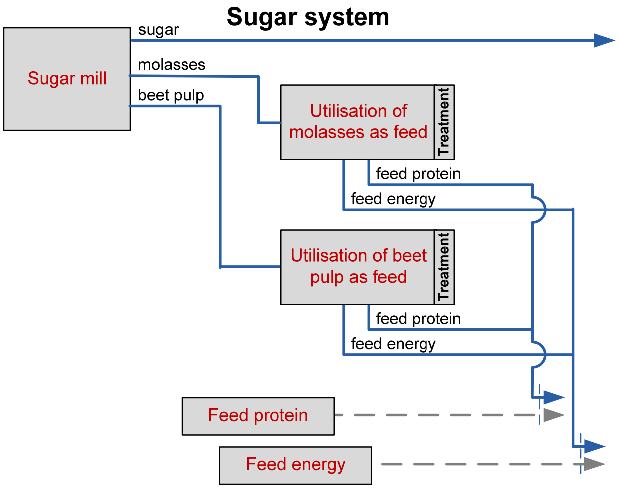

Figure 8.21: Overview of the transactions within the production system of sugar and downstream for by-products and materials for treatment until the point of substitution. Based on Nielsen et al. (2005).

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 8.22** to **Figure 8.24** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

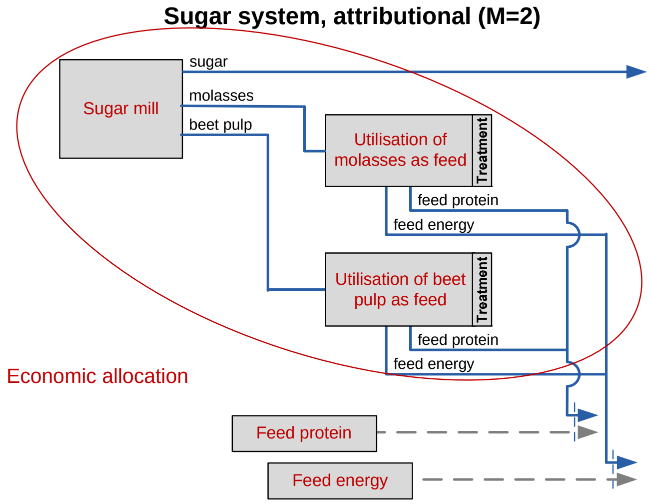

Figure 8.22: Sugar system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

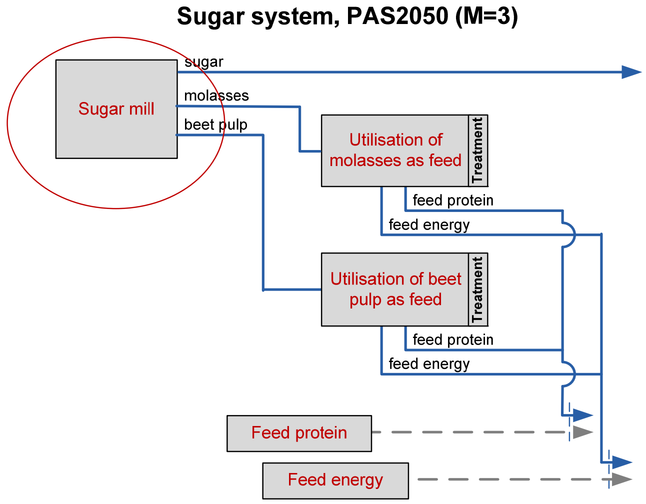

Figure 8.23: Sugar system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

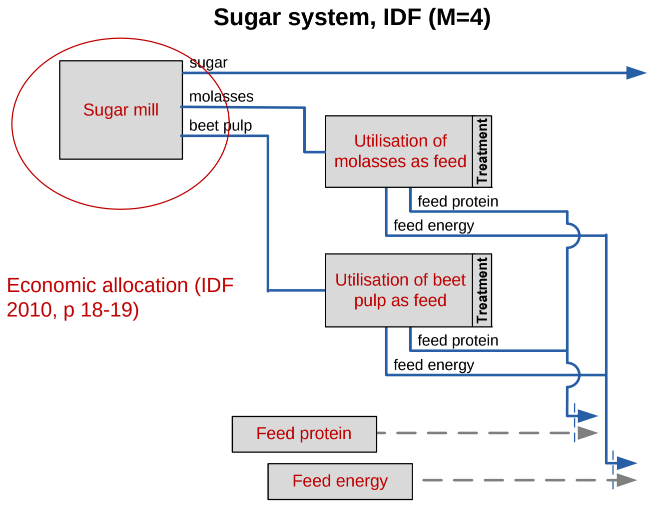

Figure 8.24: Sugar system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

8.8 Inventory of wheat flour system (wheat bran)

This section presents an overview of the wheat flour system. The system is defined from the flour mill and downstream for by-products and materials for treatment till the point of substitution.

In the Arla model wheat bran (WB) is used as cattle feedstuff. The other parts of the system are included because this is joint production with this by-product.

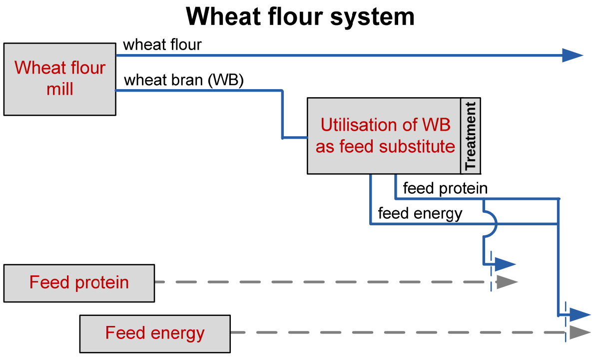

Figure 8.25: Overview of the transactions within the production system of wheat flour and downstream for by-products and materials for treatment until the point of substitution. Based on Nielsen et al. (2005).

As described in **chapter 5.3** and **Table 4.1** allocation is carried out at different points (allocation type I and II) depending on the applied switch mode. In **Figure 8.26** to **Figure 8.28** the system boundaries for the switch modes for average/allocation attributional, PAS2005 and IDF are illustrated.

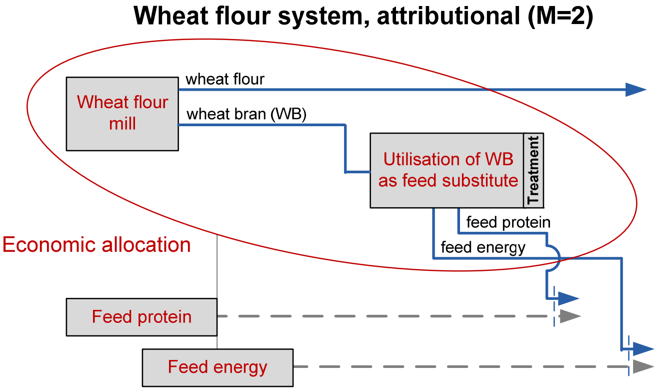

Figure 8.26: Wheat flour system: system boundaries for the average/allocation attributional switch mode. All allocations are carried at the point of substitution.

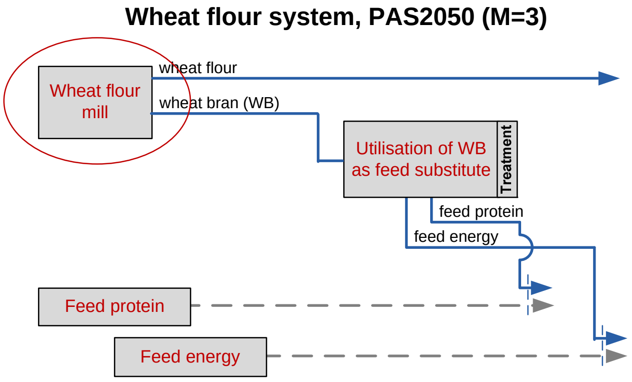

Figure 8.27: Wheat flour system: system boundaries for the PAS2005 switch mode. Allocations are carried as type I and II depending on the activities.

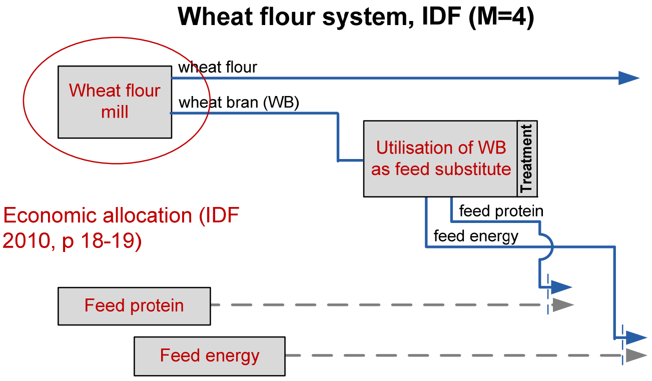

Figure 8.28: Wheat flour system: system boundaries for the IDF switch mode. Allocations are carried as type I and II depending on the activities.

9 General activities: markets, energy, transport and indirect land use change

9.1 Markets for protein and energy feed

In some cases, demand for feed purchased on the market is only specified in terms of quantity of protein feed or energy feed – regardless of the source of protein and energy. These activities are defined in the following. It should be noted that the feed market described here only regards unspecified purchased feed and thereby not specified feedstuff or feedstuff grown on the milk producing farm. However, if some specified feedstuff is constrained, the modelled effect of purchasing this feed will be the generic markets for energy and protein feed.

The protein market receives protein containing feed from several feedstuffs. However, the only source of protein feed traded on the market which is not a by-product fully determined by the demand for other products is soybean meal. In parallel, the market for energy feed receives energy containing feed from several feedstuffs, but the only energy feed which is not a by-product determined by the demand for other products is grain crops. In **chapter 7.2**, the cheapest source of grain crops and thereby the most competitive and most relevant grain crop for feed is identified as barley.

Feedstuff is demanded on direct markets for specific feedstuff, as well as they are demanded on generic markets for protein feed and energy feed. When a specific feedstuff is demanded, it is the market for this product that is affected, e.g. 1 kg soybean meal. When a generic protein or energy feed is demanded, it is the generic market for protein or energy that is affected, e.g. 1 kg protein or 1 feed unit energy feed. The generic market may be a mix of specific products. In order to distinguish between these two types of demand (specific and generic) some intermediate activities are created to transform the specific feedstuffs (1 kg soybean meal and 1 kg barley) to generic feed (quantity of protein and energy feed). These intermediate activities have only one product input (oil meal or grain crop) and two product outputs; protein and energy feed. The reference product of the soybean meal is the protein and the reference product of the barley is energy feed. The established activities are illustrated in **Table 9.1**.

Table 9.1: Activities and product flows in the feed market. Reference products are marked with bold text.

			market activity	market activity
Activities **Products**	**Soybean meal to generic market for feed**	**Grain crops to generic market for feed**	**Protein feed**	**Energy feed**
SUPPLY				
Protein feed	**X**	X	**X**	
Energy feed	X	**X**		**X**
USE				
Soybean meal	X			
Grain crops		X		
Soybean meal to generic market for feed			X	
Grain crops to generic market for feed				X

9.2 Markets for cattle meat

The market for cattle meat is affected when the milk system supplies cattle meat as a by-product. Notice that this is not considered in the switch modes for average/allocation, PAS2050 and IDF.

As described in **chapter 6.2**, Brazilian beef is identified as the most likely affected supplier, when the demand for cattle is changed. The identification of Brazilian beef as the margin source of cattle meat is associated with significant uncertainties. Therefore, sensitivity analyses are presented where Danish and Swedish beef is affected by the Danish and Swedish milk systems respectively. This is presented in **chapter 11**.

9.3 Markets for electricity

Electricity is used in most life cycle stages of milk production. Electricity markets are generally regarded as being national because electricity is regulated through national energy investment plans. In the long term national capacity follows national demand. There may be significant trade between countries but over a year (or longer period of time) this typically levels out, e.g. dry years in Norway causes increased import of electricity to Norway from Denmark, and windy years causes increased export of electricity from Denmark to its neighbour countries.

One market for electricity is defined per country. This market can then have inputs of electricity from different activities:

1. Coal electricity
2. Gas electricity
3. Oil electricity
4. Hydro electricity
5. Nuclear electricity
6. Wind electricity
7. Biomass electricity
8. Import (defined by a foreign electricity market)

The markets for electricity (and the inventory modelling) is further described in Dalgaard and Schmidt (2012) and in detail in Schmidt et al. (2011).

9.4 Utilisation of crop residues for energy purposes

When crop residues (straw) are removed from the field and sent to utilisation for energy purposes, this is implemented in the inventory framework as of **chapter 3** as illustrated in **Figure 9.1**.

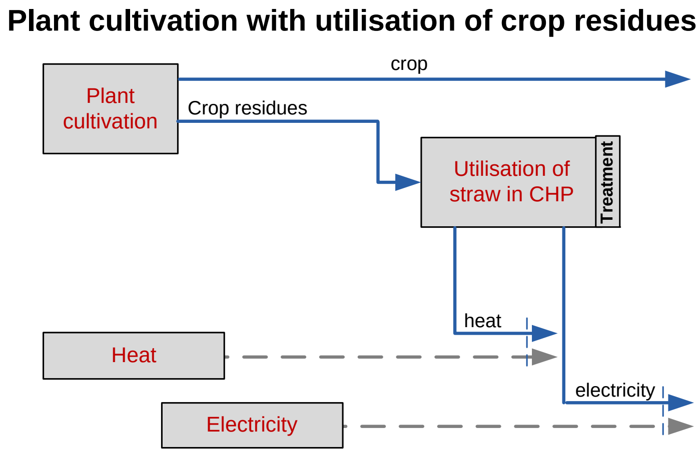

Figure 9.1: Overview of the utilisation of crop residues system.

9.5 Indirect land use changes (ILUC)

Indirect land use changes are caused by occupation of land mainly in the crop/pasture stage. The applied inventory data are obtained from the ILUC-project version 3 (Schmidt et al. 2012). The ILUC-project enables for applying consequential as well as attributional modelling assumptions. In the following the method for modelling ILUC is very briefly described.

According to the Peters et al. (2012), around 9% of global carbon emissions in 2010 originated from deforestation. Often, these emissions are not addressed in life cycle assessment (LCA) because there is a missing link between the use of land in one region of the world, e.g. for arable cropping, and expansion of arable land in another region of the world, i.e. often deforestation. The link between use of land (e.g. occupation of 1 hectare year) to deforestation and related emissions (mainly due to change in carbon stock) are referred to as indirect land use changes (ILUC). The purpose of the current project is to provide a model and data to establish the missing link, mentioned above, to enable for inclusion of ILUC in LCA modelling. In the current report, ILUC is defined as the upstream consequences of the occupation of land, regardless of what you do to it. Indirect land use changes are upstream life cycle impacts of an activity which induces the land use change whereas direct land use changes take place only in the land transforming activity.

The overall concept of the model is that it is assumed that the current use of land reflects the current demand for land, and that land use changes are caused by changes in demand for land. This concept is equivalent to all other modelling in life cycle inventory, i.e. the demand for a product determines the production volume. The market for land is defined as a service that supplies capacity for production of biomass. This capacity can be obtained from the market, which has inputs from different suppliers, e.g. expansion of land (such as deforestation) and intensification.

The presented model is applicable to all regions in the world and to all types of land use. The standard reference flow of the use of land; 'land tenure' is the land's production capacity, measured in kg NPP$_0$. This can easily be converted to occupation (ha yr).

Initially, the model accounts for all land use changes as of official statistics. Thus, the starting point is the total global observed land use changes. This is done by the establishment of a land use change transition matrix. The land use change transition matrix is mainly based on FAO's Global Forest Resources Assessment (FAO 2010).

Distinction is made between different markets for land, e.g. land suitable for arable cropping, land suitable for intensive forestry etc.

The land tenure market activities have four types of inputs: land already in use, expansion, intensification and crop displacement. The exchanges with the environment (e.g. CO_2 from deforestation) that causes the impacts of the ILUC are present within these four activities. The emissions related to deforestation are based on IPCC Guidelines for national greenhouse gas inventories (IPCC 2006). The emissions related to intensification are based on Schmidt (2008).

10 Life cycle impact assessment

In this chapter the results of the CF baseline for Denmark and Sweden are presented. This includes results for different switch modes as well as detailed contribution and sensitivity analyses. The results presented in **chapter 10.1** to **10.4** are summarized in **Figure 10.1**.

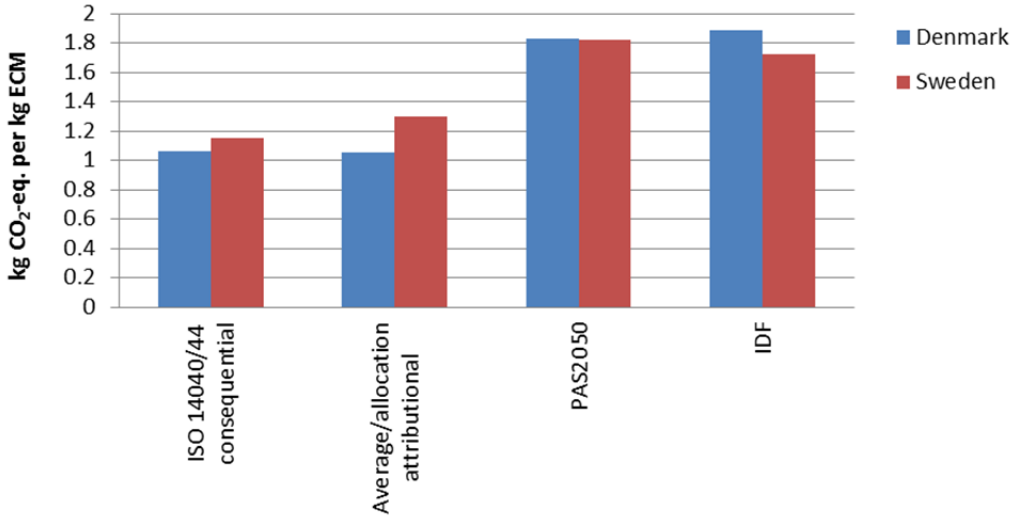

Figure 10.1: Summary of the results; GHG-emissions for 1 kg ECM for the Danish and Swedish baseline.

The results are interpreted more in detail for the ISO14040/44 consequential switch mode than for the other switch modes. The purpose of interpreting the results is mainly to understand the underlying explanations of the result. Since the consequential switch mode represents interlinked actual activities (i.e. non allocated activities), a thorough interpretation of these results is most meaningful. Else differences in contributions should be explained by more or less arbitrary/normative allocation factors as of prescribed by the different standards instead of factual differences in the production systems.

The results tables are divided into three major parts;

1) direct emissions of CH_4 and N_2O from the animals and their manure (from housing and storage)
2) upstream emissions from the production of feed, land use changes, utilisation of manure as organic fertiliser, fuels and their combustion etc. Note that services and capital goods are included in these figures.
3) Avoided emissions related to the substituted beef production caused by the supply of meat from the milk system

In addition, the results are shown with lower degrees of completeness below the core table.

In the following, all results tables are organised in this way. However, since the switch modes: average, PAS2050 and IDF do not involve substitution, the part of the results table involving the avoided emissions related to the beef are only included for the ISO14040/44 consequential switch mode.

Below in Table 10.1, there is a detailed description of the different items in the results tables.

Table 10.1: Description of what is included in the different items in the results tables.

Contributing items	Activity
Direct emissions (milk system)	
CH_4, enteric fermentation	CH_4 emitted directly from animal
CH_4, manure handling and storage	CH_4 emitted from manure from the point when the manure leaves the animal until the manure is: - applied to land (manure from housing/storage), or: - decayed in pasture system (manure deposited on pasture)
N_2O direct	N_2O emitted directly from manure from the point when the manure leaves the animal until the manure is applied in field/deposited on pasture
N_2O indirect	N_2O emitted indirectly from NH_3 and NO_3 losses from manure from the point when the manure leaves the animal until the manure is applied in field/deposited on pasture
Emissions outside the animal activities (incl. capital goods and services)	
Feed inputs, excl. iLUC	**Emissions from own feed crops and purchased crops and feedstuff:** N_2O from mineral fertiliser and manure applied/deposited in field (direct from applied N and indirect from NH_3 and NO_3 losses) Crop farm capital goods and services Fertiliser production incl. capital goods and services Traction incl. capital goods and services Fuels incl. combustion and other emissions in foods industry
iLUC	CO_2 and N_2O from deforestation Intensification (direct/indirect N_2O, fertiliser, traction)
Manure land appl.	Depends on switch!
Fuels incl. combustion	Fuels (incl. combustion) directly used in milk system. Fuels relating to crops are not included here.
Electricity	Electricity directly used in milk system, e.g. for milking machine and housing. Electricity for relating to crops is not included here.
Transport	Transport of feed to milk farm
Destruction of fallen cattle incl. subst. energy	Transport of animals to destruction, energy use at destruction, by-products from destruction
Farm, capital goods	Capital goods relating to milk system
Farm, services	Services relating to milk system

10.1 ISO14040/44 – consequential modelling

In **Table 10.2** and **Table 10.3** the GHG-emissions for the Danish and Swedish baselines are presented. The total GHG-emissions related to 1 kg Danish and Swedish ECM are 1.06 kg CO_2-eq. and 1.15 kg CO_2-eq. respectively.

Of the total GHG-emissions at 1.06 kg CO_2-eq., 0.682 kg CO_2-eq. are direct emission in the four animal activities in the milk system. 2.26 kg CO_2-eq. relates to upstream activities, and the avoided emissions related to the substituted beef system accounts for -1.88 kg CO_2-eq.

The product system and the contributing activities for Denmark are illustrated in **Figure 10.2**. The product system and the contributing figure (as **Figure 10.2**) are only shown for Denmark. The purpose is to visually illustrate how the most important activities are linked and to give an impression of where in the system the most significant flows occur. The figure provides the same kind of information as **Table 10.2**, but just in another format, and less complete (not all contributions to the total result are included in **Figure 10.2**). In the figure the thickness of the arrows represent the accumulated (that means including upstream life cycle activities) importance of the activities. Red arrows represent GHG-emissions with positive sign and green arrows represent avoided emissions.

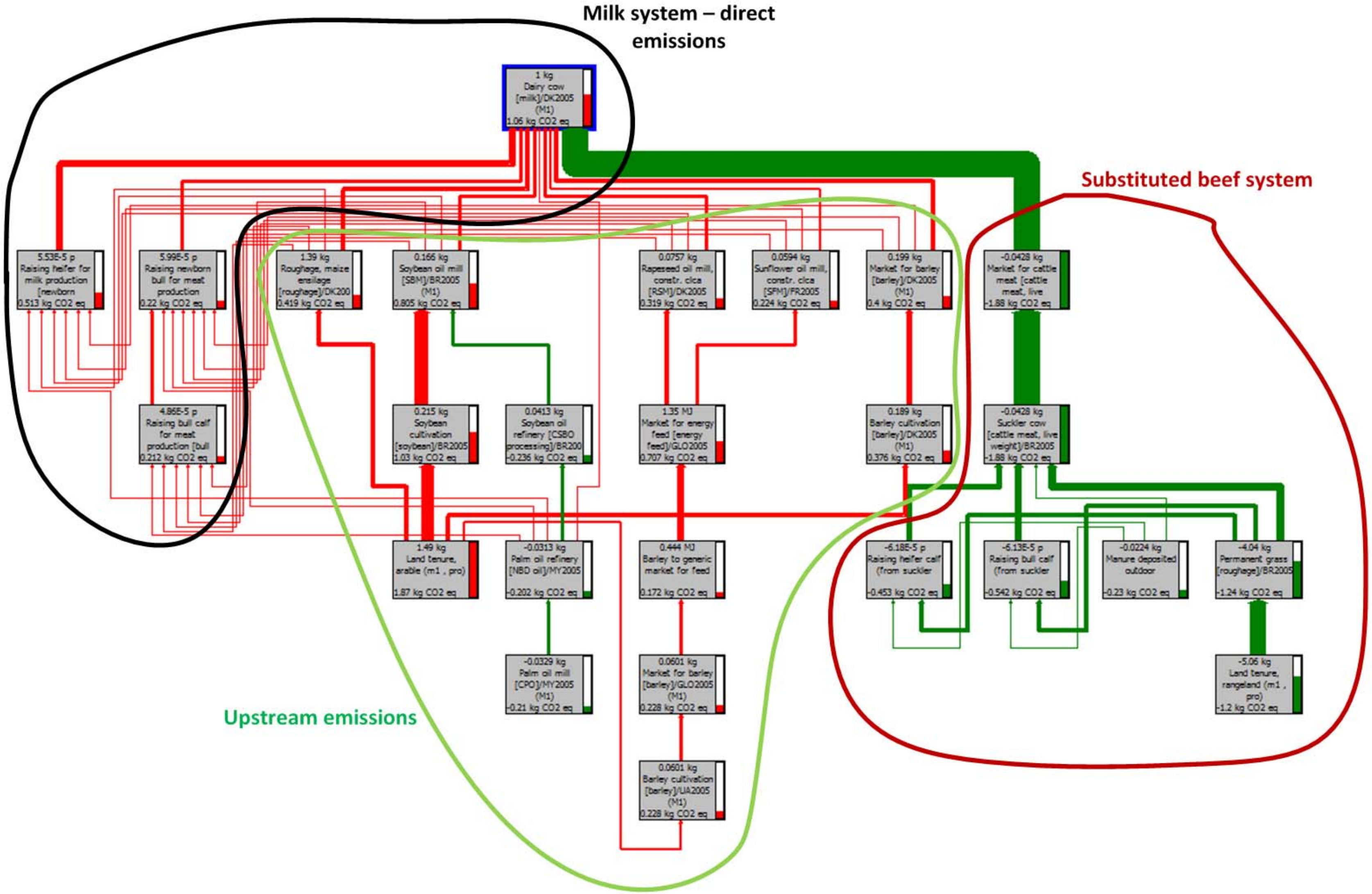

Figure 10.2: Flow chart illustrating the major contributing activities for GHG-emissions for 1 kg ECM Danish milk. The three parts of the results table (**Table 10.2**) are indicated. The flow chart is produced in SimaPro 7.3. The shown processes account for 89% of the total GHG-emissions.

Table 10.2: GHG-emissions for 1 kg ECM milk, Danish baseline. Switch: ISO14044: consequential

Denmark	Milking cow	Raising heifer	Raising newborn bull	Raising bull	Total	Total
Direct emissions						
CH_4, enteric fermentation	0.414	0.094	0.00138	0.0380	**0.548**	**0.682**
CH_4, manure handling and storage	0.0697	0.00838	0.000347	0.00764	**0.0860**	
N_2O direct	0.0312	0.00605	0.000274	0.00459	**0.0422**	
N_2O indirect	0.00524	0.000731	0.0000216	0.000474	**0.00647**	
Emissions outside the animal activities (incl. capital goods and services)						
Feed inputs, excl. ILUC	0.170	0.0388	0.000568	0.0156	**0.225**	**2.26**
ILUC related to feed	1.47	0.336	0.00492	0.135	**1.95**	
Manure land appl. incl. subst. mineral fert.	-0.0353	-0.00125	-0.0000160	-0.00165	**-0.0382**	
Fuels incl. combustion	0.00994	0.00229	0.000255	0.00175	**0.0142**	
Electricity	0.0369	0	0	0	**0.0369**	
Transport	0.0138	0.00315	0.0000461	0.00127	**0.0183**	
Destruction of fallen cattle incl. subst. energy	-0.00314	-0.000530	-0.000269	-0.000414	**-0.00435**	
Farm, capital goods	0.0113	0.0113	0.000580	0.00397	**0.0271**	
Farm, services	0.0149	0.0150	0.000767	0.00525	**0.0359**	
Substituted beef system (incl. capital goods and services)						
Direct emissions (CH_4 and N_2O)					**-0.399**	**-1.88**
Feed inputs, excl. ILUC					**-0.0324**	
ILUC related to feed					**-1.20**	
Other					**-0.245**	
Total						**1.06**

Results with lower degree of completeness	
Total (result without ILUC)	**0.316**
Total (result without ILUC and services)	**0.254**
Total (result without ILUC, services and capital goods)	**0.199**

It appears from the **Table 10.2** that the most important contributions are ILUC (sum of ILUC from several crops/grass), avoided beef (sum of contributions from several activities within the beef system), direct emissions from the animal activities (where enteric fermentation is the most important), and the production of feedstuff (sum of all feedstuff incl. upstream activities such as diesel for traction, farm capital goods and services, and production of fertiliser and pesticides).

Transport of materials (mainly feed) to the milk farms, burning of diesel for traction etc., and electricity do not contribute significantly to the overall result. Also the inputs of capital goods and services to the milk system are not major contributors to the overall result. It appears that the land application of manure has a negative contribution. This is because the avoided emissions from the substituted production of mineral fertilisers are larger than the direct emissions related to the application of the manure on crops. Also the destruction of animals is associated with a negative contribution because the by-products from the activity substitutes energy that alternatively would have been produced by the burning of fossil fuels.

In the lower part of **Table 10.2** the results are shown with lower degrees of completeness. Obviously, the results without ILUC are significantly lower than when including ILUC. The results without capital goods and services show that the overall result is only affected with approximately 0.117 kg CO_2-eq. by the inclusion/exclusion of capital goods and services.

The contribution from ILUC includes contributions from transformation of land not in use (primary and secondary forest) to arable land and from intensification of land already in use. The major contribution is the one from intensification, where the emissions from additional fertiliser application are the most significant source of the GHG-emissions. The inventory of ILUC (consequential modelling) is further described in Schmidt et al. (2012).

Table 10.3: GHG-emissions for 1 kg ECM milk, Swedish baseline. Switch: ISO14044: consequential

Sweden	**Milking cow**	**Raising heifer**	**Raising newborn bull**	**Raising bull**	**Total**	**Total**
Direct emissions						
CH_4, enteric fermentation	0.428	0.107	0.00242	0.0958	**0.633**	
CH_4, manure handling and storage	0.0553	0.00793	0.000348	0.0138	**0.0774**	
N_2O direct	0.0277	0.00597	0.000281	0.00809	**0.0420**	
N_2O indirect	0.00335	0.000795	0.0000565	0.00163	**0.00583**	**0.758**
Emissions outside the animal activities (incl. capital goods and services)						
Feed inputs, excl. ILUC	0.357	0.089	0.00202	0.0799	**0.528**	
ILUC related to feed	1.45	0.362	0.00819	0.324	**2.14**	
Manure land appl. incl. subst. mineral fert.	-0.0389	-0.00619	-0.0001363	-0.00332	**-0.0486**	
Fuels incl. combustion	0.0100	0.00300	0.000330	0.00253	**0.0159**	
Electricity	0.0133	0	0	0	**0.0133**	
Transport	0.0135	0.00339	0.0000766	0.00303	**0.0200**	
Destruction of fallen cattle incl. subst. energy	-0.00318	-0.00150	-0.000347	-0.00144	**-0.00648**	
Farm, capital goods	0.0115	0.0126	0.000748	0.00838	**0.0332**	
Farm, services	0.0152	0.0166	0.000990	0.0111	**0.0439**	**2.74**
Substituted beef system (incl. capital goods and services)						
Direct emissions (CH_4 and N_2O)					**-0.498**	
Feed inputs, excl. ILUC					**-0.0403**	
ILUC related to feed					**-1.50**	
Other					**-0.306**	**-2.34**
Total						**1.15**

Results with lower degree of completeness	
Total (result without ILUC)	**0.508**
Total (result without ILUC and services)	**0.423**
Total (result without ILUC, services and capital goods)	**0.346**

The overall results, i.e. the relative magnitude of different contributing activities, for Swedish milk in **Table 10.3** are not significantly different from the ones for Danish milk in **Table 10.2**. Therefore, the contributions to the total result for Swedish milk are not further elaborated. However, the total result for Swedish milk is approximately 8% higher than Danish milk. The underlying reasons for this difference are described in the following.

Table 10.4: Comparison of the GHG-emissions from 1 kg ECM for Danish and Swedish milk when using ISO14040/44 consequential switch mode.

Contribution	Danish milk		Swedish milk		Explanation of difference
Direct emissions					
CH_4, enteric fermentation	0.548	**0.682**	0.633	**0.758**	The direct emissions are higher for Sweden. This is because the activity ‘raising bull’ contributes more in Sweden. The reason for this is that these animals are kept for longer time and grown bigger before they are slaughtered in Sweden than in Denmark.
CH_4, manure handling and storage	0.0860		0.0774		
N_2O direct	0.0422		0.0420		
N_2O indirect	0.00647		0.00583		
Emissions outside the animal activities (incl. capital goods and services)					
Feed inputs, excl. ILUC	0.225	**2.26**	0.528	**2.74**	The contributions from activities outside the animal activities are higher for Sweden. The explanation of this is partly the same as for the animal activities (see above) and partly because the Swedish cows eat relatively more permanent grass and less maize ensilage and grain crops. The GHG-emissions related to permanent grass are higher than of maize ensilage and grain crops, see **Table 10.5**.
ILUC related to feed	1.95		2.14		
Manure land appl. incl. subst. mineral fert.	-0.0382		-0.0486		
Fuels incl. combustion	0.0142		0.0159		
Electricity	0.0369		0.0133		
Transport	0.0183		0.0200		
Destruction of fallen cattle incl. subst. energy	-0.00435		-0.00648		
Farm, capital goods	0.0271		0.0332		
Farm, services	0.0359		0.0439		
Substituted beef system (incl. capital goods and services)					
Direct emissions (CH_4 and N_2O)	-0.399	**-1.88**	-0.498	**-2.34**	The avoided emissions in Sweden are higher than in Denmark, because the meat output from the Swedish milk system is higher than in Denmark. The higher meat output in Sweden is achieved by letting the bulls grow bigger before they are slaughtered.
Feed inputs, excl. ILUC	-0.0324		-0.0403		
ILUC related to feed	-1.20		-1.50		
Other	-0.245		-0.306		
Total		**1.06**		**1.15**	

Table 10.5: GHG-emissions for the production of different feedstuff used in Denmark and Sweden. The results are shown per 1 kg dry matter (dm) feedstuff, and they are calculated using ISO14040/44 consequential switch mode.

Feedstuff	**Denmark** kg CO2-eq./kg dm	**Sweden** kg CO2-eq./kg dm
Permanent grass	5.55	4.44
Rotation grass	1.78	1.60
Roughage, maize ensilage	0.911	0.955
Barley	2.33	2.28
Oat	2.71	2.67
Wheat bran (soymeal and barley affected)	3.56	
Palm kernel meal (soymeal and barley affected)	3.32	
Palm oil	5.83	
Rapeseed meal (soymeal and barley affected)	4.73	
Soybean meal	5.55	
Beet pulp, dried (soymeal and barley affected)	4.02	
Molasses (soymeal and barley affected)	3.93	
Corn	2.10	

10.2 Average/allocation – attributional modelling

In **Table 10.7** and **Table 10.8** the GHG-emissions for the Danish and Swedish baselines are presented for the average/allocation switch mode. The total GHG-emissions related to 1 kg Danish and Swedish ECM are 1.05 kg CO_2-eq. and 1.30 kg CO_2-eq. respectively. This result is not significantly different from the results when applying consequential modelling. But it should be noted, that these 'similar' results are more a matter of incident than an indication that similar results can be expected when using consequential and attributional modelling assumptions. The differences become very clear when comparing the results; below in **Table 10.6** the results for 1 kg ECM from Denmark are compared for consequential and attributional modelling. Almost all contributions in the attributional modelling switch differ substantially from the ones in the consequential modelling switch. In general the contributions in the columns for the attributional modelling are approximately 82% of the ones in the consequential modelling. This is because the attributional modelling uses an allocation factor of approximately 82% to the milk. However, not all contributions are just scaled with 82%, e.g. the ILUC differ with orders of magnitude. This is explained further below **Table 10.6**.

Table 10.6: Comparison of the GHG-emissions from 1 kg ECM for Danish milk when using consequential and attributional modelling assumptions.

Denmark	**ISO1440/44 consequential**		**Average/allocation attributional**	
Direct emissions				
CH_4, enteric fermentation	0.548	**0.682**	0.447	**0.557**
CH_4, manure handling and storage	0.0860		0.0702	
N_2O direct	0.0422		0.0344	
N_2O indirect	0.00647		0.00528	
Emissions outside the animal activities (incl. capital goods and services)				
Feed inputs, excl. ILUC	0.225	**2.26**	0.328	**0.497**
ILUC related to feed	1.95		0.00539	
Manure land appl. incl. subst. mineral fert.	-0.0382		0.00259	
Fuels incl. combustion	0.0142		0.0117	
Electricity	0.0369		0.0820	
Transport	0.0183		0.0150	
Destruction of fallen cattle incl. subst. energy	-0.00435		0.000304	
Farm, capital goods	0.0271		0.0225	
Farm, services	0.0359		0.0297	
Substituted beef system (incl. capital goods and services)				
Direct emissions (CH_4 and N_2O)	-0.399	**-1.88**	n.a.	n.a.
Feed inputs, excl. ILUC	-0.0324		n.a.	
ILUC related to feed	-1.20		n.a.	
Other	-0.245		n.a.	
Total		**1.06**		**1.05**

The contribution from ILUC is significant lower than in the ISO 14040/44 consequential switch mode. This is because the attributional modelling of ILUC considers all inputs to the market for land (land tenure) as flexible and a market average mix is applied. The major source of arable land is the land which is already in use; the total land available for arable cropping in a year from 2000 to 2010 is around 1.6 million ha of which less than 1% is new land (Schmidt et al. 2012, p 29).

Table 10.7: GHG-emissions for 1 kg ECM milk, Danish baseline. Switch: average/allocation: attributional. 81.6% of the milk system is allocated to milk (economic allocation between milk, meat, exported animals, fertilisers from manure land application and recovered energy from the destruction of dead animals).

Denmark	Milking cow	Raising heifer	Raising newborn bull	Raising bull	Total	Total
Direct emissions						
CH_4, enteric fermentation	0.338	0.0770	0.00113	0.03104	**0.447**	
CH_4, manure handling and storage	0.0569	0.00684	0.000283	0.006238	**0.0702**	
N_2O direct	0.0255	0.00494	0.000224	0.003749	**0.0344**	
N_2O indirect	0.00428	0.000597	0.0000176	0.0003866	**0.00528**	**0.557**
Emissions outside the animal activities (incl. capital goods and services)						
Feed inputs, excl. ILUC	0.247	0.0576	0.000843	0.0232	**0.328**	
ILUC related to feed	0.00405	0.000945	0.0000138	0.000381	**0.00539**	
Manure land appl.	0.00209	0.000304	0.00000799	0.000181	**0.00259**	
Fuels incl. combustion	0.00811	0.00192	0.000214	0.00146	**0.0117**	
Electricity	0.0820	0	0	0	**0.0820**	
Transport	0.0113	0.00263	0.0000386	0.00106	**0.0150**	
Destruction of fallen cattle	0.000217	0.0000376	0.0000191	0.0000294	**0.000304**	
Farm, capital goods	0.00920	0.0095	0.000485	0.00332	**0.0225**	
Farm, services	0.0122	0.0125	0.000642	0.00439	**0.0297**	**0.497**
Total						**1.05**

Results with lower degree of completeness	
Total (result without ILUC)	**1.01**
Total (result without ILUC and services)	**0.963**
Total (result without ILUC, services and capital goods)	**0.919**

It appears from **Table 10.7** that the most important contributions are direct emissions from the animal activities (where enteric fermentation is the most important) and the production of feedstuff (sum of all feedstuff incl. upstream activities such as diesel for traction, farm capital goods and services, and production of fertiliser and pesticides). Fairly similar hotspots can be found in the references mentioned in **chapter 2**: Flysjö et al. (2011), Kristensen et al. (2011), Thomassen et al. (2008), and Gerber et al. (2010). This agreement in results can be explained with the fact that the modelling assumptions applied in these references are fairly similar to the ones as applied in the average/allocation attributional modelling switch here. Of course there are deviations, but this does not significantly affect the general agreement in results.

Transport of materials (mainly feed) to the milk farms, burning of diesel for traction etc., and electricity do not contribute significantly to the overall result. Also the inputs of capital goods and services to the milk system are not major contributors to the overall result.

In the lower part of the table, the results are shown with lower degrees of completeness. The results without capital goods and services show that the overall result is not affected significantly by the inclusion/exclusion of capital goods and services.

Table 10.8: GHG-emissions for 1 kg ECM milk, Swedish baseline. Switch: average/allocation: attributional. 83.9% of the milk system is allocated to milk (economic allocation between milk, meat, exported animals, fertilisers from manure land application and recovered energy from the destruction of dead animals).

Sweden	Milking cow	Raising heifer	Raising newborn bull	Raising bull	Total	Total
Direct emissions						
CH_4, enteric fermentation	0.359	0.0897	0.00203	0.0803	**0.531**	**0.636**
CH_4, manure handling and storage	0.0464	0.00665	0.000292	0.0116	**0.0649**	
N_2O direct	0.0232	0.00501	0.000236	0.00679	**0.0353**	
N_2O indirect	0.00281	0.000667	0.0000474	0.00137	**0.00489**	
Emissions outside the animal activities (incl. capital goods and services)						
Feed inputs, excl. ILUC	0.342	0.0878	0.00198	0.0785	**0.510**	**0.667**
ILUC related to feed	0.0331	0.00850	0.000192	0.00760	**0.0494**	
Manure land appl.	0.00213	0.000439	0.00001133	0.000346	**0.00293**	
Fuels incl. combustion	0.00841	0.00258	0.000283	0.00217	**0.0134**	
Electricity	0.00777	0	0	0	**0.0078**	
Transport	0.0113	0.00291	0.0000658	0.00260	**0.0169**	
Destruction of fallen cattle	0.000184	0.0000892	0.0000206	0.0000855	**0.000380**	
Farm, capital goods	0.00964	0.0108	0.000643	0.00720	**0.0283**	
Farm, services	0.0128	0.0143	0.000851	0.00953	**0.0374**	
Total						**1.30**

Results with lower degree of completeness	
Total (result without ILUC)	**1.25**
Total (result without ILUC and services)	**1.18**
Total (result without ILUC, services and capital goods)	**1.12**

The differences between Danish and Swedish milk are explained in **chapter 10.1**.

10.3 PAS2050

In **Table 10.9** and **Table 10.10** the GHG-emissions for the Danish and Swedish baselines are presented for the PAS2050 switch mode. The total GHG-emissions related to 1 kg Danish and Swedish ECM are 1.83 kg CO_2-eq. and 1.82 kg CO_2-eq. respectively. It appears that these results are significantly higher than the results when using the switch modes for ISO14040/44 consequential and average/allocation attributional where the results fall within the range 1.05 to 1.30 kg CO_2-eq. per kg ECM. The modelling assumptions in the PAS2050 switch mode is to a large extent similar to the average/allocation attributional switch mode. Therefore, a similar result could be expected. This is also the case for all contributions except the contribution from land use changes and less pronounced the contribution from feed inputs. The difference for the feed inputs is caused by a lesser degree of completeness (capital goods and services) for the PAS2050 switch mode, where the contribution is lower than of the average/allocation attributional switch mode. The reason for the high total results for the PAS2050 switch mode is the contribution from land use changes in soy cultivation in Brazil (and minor contributions from oil palm in Malaysia). It should be noticed that the way land use changes are modelled in PAS2050 are direct land use changes (DLUC) and by applying a 20 year historical amortisation period. This approach is substantially different from the modelling of ILUC which is applied in the switch modes for ISO14040/44 consequential and average/allocation attributional. DLUC here only considers impacts from cultivated fields that have been transformed within the recent 20 years. Hence, the cultivation of old arable land is not associated with any land use change effects.

Table 10.9: GHG-emissions for 1 kg ECM milk, Danish baseline. Switch: PAS2050. 84.4% of the milk system is allocated to milk (economic allocation between milk, meat and exported animals).

Denmark	**Milking cow**	**Raising heifer**	**Raising newborn bull**	**Raising bull**	**Total**	**Total**
Direct emissions						
CH_4, enteric fermentation	0.349	0.0796	0.00117	0.03210	**0.462**	**0.576**
CH_4, manure handling and storage	0.0588	0.00707	0.000293	0.006450	**0.0726**	
N_2O direct	0.0264	0.00510	0.000231	0.00388	**0.0356**	
N_2O indirect	0.00442	0.000617	0.0000182	0.000400	**0.00546**	
Emissions outside the animal activities (excl. capital goods and services)						
Feed inputs, excl. DLUC	0.194	0.0442	0.000647	0.0178	**0.257**	**1.25**
DLUC (soybean and oil palm)	0.668	0.152	0.00223	0.0614	**0.884**	
Manure land appl.	0.00211	0.000300	0.00000787	0.000178	**0.00260**	
Fuels incl. combustion	0.00819	0.00189	0.000210	0.00144	**0.0117**	
Electricity	0.0832	0	0	0	**0.0832**	
Transport	0.00901	0.00205	0.0000301	0.000828	**0.0119**	
Destruction of fallen cattle	0.000150	0.0000254	0.0000129	0.0000198	**0.000209**	
Total						**1.83**

Results with lower degree of completeness	
Total (result without DLUC)	**0.942**

Table 10.10: GHG-emissions for 1 kg ECM milk, Swedish baseline. Switch: PAS2050. 86.9% of the milk system is allocated to milk (economic allocation between milk, meat and exported animals).

Sweden	**Milking cow**	**Raising heifer**	**Raising newborn bull**	**Raising bull**	**Total**	**Total**
Direct emissions						
CH_4, enteric fermentation	0.372	0.0929	0.00210	0.0832	**0.550**	**0.659**
CH_4, manure handling and storage	0.0480	0.00689	0.000302	0.0120	**0.0672**	
N_2O direct	0.0241	0.00519	0.000244	0.00703	**0.0365**	
N_2O indirect	0.00291	0.000690	0.0000491	0.00142	**0.00506**	
Emissions outside the animal activities (excl. capital goods and services)						
Feed inputs, excl. DLUC	0.316	0.0793	0.00179	0.0709	**0.468**	**1.16**
DLUC (soybean and oil palm)	0.440	0.110	0.00249	0.0986	**0.651**	
Manure land appl.	0.00215	0.000433	0.0000112	0.000342	**0.00294**	
Fuels incl. combustion	0.00850	0.00254	0.000279	0.00215	**0.0135**	
Electricity	0.00702	0	0	0	**0.0070**	
Transport	0.00908	0.00227	0.0000514	0.00203	**0.0134**	
Destruction of fallen cattle	0.000114	0.0000538	0.0000124	0.0000515	**0.000232**	
Total						**1.82**

Results with lower degree of completeness	
Total (result without DLUC)	**1.16**

Comparing the result for Denmark and Sweden shows that the results are almost similar, i.e. 1.83 and 1.82 kg CO_2-eq. respectively. In **chapter 10.1** it is explained that the results are generally higher for Sweden. Then it apparently seems strange that this is not the case when applying the PAS2050 switch mode. The explanation for this is to be found in the way land use changes are modelled; if the results without land use changes (below the main parts of the tables) are compared for Denmark and Sweden, then it appears that the result for Sweden is higher – as expected.

The reason for the difference is that the Danish milk system uses more soybean meal than the Swedish system. The way land use changes are modelled in PAS2050 allocates the burden of land occupation to cultivated land under recently (20 years) transformed forest only. In the ISO 14040/44 consequential and the average/allocation attributional switch modes all occupation of land is assumed to contribute to land use changes. Therefore, in the PAS2050 switch mode, just small uses of crops from fields that have potentially (we don't know the exact field) been transformed from forest within the recent 20 years contributes significantly to the results; e.g. 1 kg soybean meal contributes with 14.4 kg CO_2-eq. of which 14.1 kg CO_2-eq. is related to DLUC.

10.4 IDF Guideline

In **Table 10.11** and **Table 10.12** the GHG-emissions for the Danish and Swedish baselines are presented for the IDF switch mode. The total GHG-emissions related to 1 kg Danish and Swedish ECM are 1.89 kg CO_2-eq. and 1.72 kg CO_2-eq. respectively. As for the PAS2050 switch mode results, these results are significantly higher than the results when using the switch modes for ISO14040/44 consequential and average/allocation attributional. The explanation for the IDF switch mode results is the same as for PAS2050, i.e. the way land use changes are modelled in IDF causes high results because of the use of soybean meal and palm oil which potentially are sourced from crops grown on fields that have recently (20 years) been transformed from forest.

The results when using the IDF switch mode are slightly higher than the ones of PAS2050. The reason for this is a higher degree of completeness, i.e. capital goods and services are included.

It should be noticed that the IDF guideline (IDF 2010) does not regard the raising of bulls for meat production as part of the milk system. Subsequently, IDF applies the point of allocation just after the raising of newborn bulls where these are sold off to other farms belonging to the beef system. In **Table 10.11** and **Table 10.12** this has the effect that the column representing the raising of bulls is empty. It should be noticed that if the IDF guideline is applied at the farm level, and if a specific farm raises its bulls until they are ready for the slaughterhouse, then this should be included as part of the milk system. However, for the national baselines, it has been assumed that the smaller bulls from the milk system generally are raised for meat production at other farms in the beef system.

Table 10.11: GHG-emissions for 1 kg ECM milk, Danish baseline. Switch: IDF. 86.3% of the milk system is allocated to milk (biophysical founded allocation between milk and meat). Notice that IDF does not define the raising of bulls from the milk system as part of the milk system.

Denmark	**Milking cow**	**Raising heifer**	**Raising newborn bull**	**Raising bull**	**Total**	**Total**
Direct emissions						
CH_4, enteric fermentation	0.357	0.0815	0.00119	n.a.	**0.440**	**0.545**
CH_4, manure handling and storage	0.0601	0.00724	0.000300	n.a.	**0.0677**	
N_2O direct	0.0270	0.00522	0.000237	n.a.	**0.0324**	
N_2O indirect	0.00452	0.000631	0.0000186	n.a.	**0.00517**	
Emissions outside the animal activities (incl. capital goods and services)						
Feed inputs, excl. DLUC	0.225	0.0514	0.000752	n.a.	**0.277**	**1.34**
DLUC (soybean and oil palm)	0.735	0.167	0.00245	n.a.	**0.905**	
Manure land appl.	0.00221	0.000314	0.00000825	n.a.	**0.00254**	
Fuels incl. combustion	0.00858	0.00198	0.000221	n.a.	**0.0108**	
Electricity	0.0867	0	0	n.a.	**0.0867**	
Transport	0.0119	0.00272	0.0000398	n.a.	**0.0147**	
Destruction of fallen cattle incl. subst. energy	-0.00268	-0.000453	-0.000230	n.a.	**-0.00336**	
Farm, capital goods	0.00973	0.00977	0.000501	n.a.	**0.0200**	
Farm, services	0.0129	0.0129	0.000662	n.a.	**0.0265**	
Total						**1.89**

Results with lower degree of completeness	
Total (result without DLUC)	**0.981**
Total (result without DLUC and services)	**0.937**
Total (result without DLUC, services and capital goods)	**0.896**

Table 10.12: GHG-emissions for 1 kg ECM milk, Swedish baseline. Switch: IDF. 86.3% of the milk system is allocated to milk (biophysical founded allocation between milk and meat). Notice that IDF does not define the raising of bulls from the milk system as part of the milk system.

Sweden	Milking cow	Raising heifer	Raising newborn bull	Raising bull	Total	Total
Direct emissions						
CH_4, enteric fermentation	0.370	0.0924	0.00209	n.a.	**0.464**	
CH_4, manure handling and storage	0.0477	0.00685	0.000300	n.a.	**0.0549**	
N_2O direct	0.0239	0.00515	0.000243	n.a.	**0.0293**	
N_2O indirect	0.00289	0.000686	0.0000488	n.a.	**0.00363**	**0.552**
Emissions outside the animal activities (incl. capital goods and services)						
Feed inputs, excl. DLUC	0.360	0.0901	0.00204	n.a.	**0.452**	
DLUC (soybean and oil palm)	0.503	0.126	0.00285	n.a.	**0.632**	
Manure land appl.	0.00219	0.000441	0.0000114	n.a.	**0.00265**	
Fuels incl. combustion	0.00866	0.00259	0.000285	n.a.	**0.0115**	
Electricity	0.00800	0	0	n.a.	**0.00800**	
Transport	0.0117	0.00293	0.0000661	n.a.	**0.0147**	
Destruction of fallen cattle incl. subst. energy	-0.00275	-0.00130	-0.000300	n.a.	**-0.00435**	
Farm, capital goods	0.00993	0.0109	0.000646	n.a.	**0.0214**	
Farm, services	0.0131	0.0144	0.000855	n.a.	**0.0283**	**1.17**
Total						**1.72**

Results with lower degree of completeness	
Total (result without DLUC)	**1.09**
Total (result without DLUC and services)	**1.03**
Total (result without DLUC, services and capital goods)	**0.974**

As for the PAS2050 results, it appears that Danish milk performs better than Swedish milk when land use changes are not included. But comparing the results when land use is included does not leads to almost similar results as it is the case for the PAS2050 switch mode. In fact Swedish milk performs better than Danish milk. This result is the opposite as when comparing Danish and Swedish milk using the ISO 14040/44 consequential and the average/allocation attributional switch modes. The reason for this is that the raising of bulls is excluded from the inventory here in the IDF switch mode. As explained in Table 10.4 the reason why the contribution from the Danish milk system (disregarding the substituted system) is lower than of the Swedish system is that exactly the raising of bulls contributes more in Sweden. And since this is excluded in the IDF switch mode, we see that the Swedish milk performs better than the Danish milk.

10.5 Land occupation

One of the most important contributors to the overall results in **chapter 10.1** to **10.4** is ILUC or DLUC. In order to be able to assess the underlying causes of ILUC or DLUC it is required that the land occupation is known. This is summarized in **Table 10.13** for all switch modes for the Danish and Swedish baselines.

In the bottom of the table the total land occupation related to 1 kg ECM is indicated. It should be noted that the total occupation of land in the consequential switch mode is negative. This is because the substituted beef system in Brazil is associated with a very high use of land per kg meat.

Table 10.13: Overview of land occupation related to 1 kg ECM for the four switches and for Denmark and Sweden. For ILUC it is indicated which type of land tenure market that is affected (arable, rangeland or forest land), and for DLUC, the countries in which deforestation is regarded as taling place are marked with an * (Brazil for soybean and Malaysia).

			Denmark				Sweden			
Crop, country		**ILUC/DLUC**	**clca**	**alca**	**PAS2050**	**IDF**	**clca**	**alca**	**PAS2050**	**IDF**
Barley	DK	arable	0.367	0.185	0.256	0.262				
	EU	arable	0.021	0.018	0.018	0.018	0.019	0.016	0.016	0.016
	SE	arable					0.295	0.143	0.206	0.205
	UA	arable	0.274				0.267			
Corn	EU	arable	0.015	0.013	0.013	0.013	0.002	0.002	0.002	0.002
Oat	SE	arable					0.292	0.184	0.227	0.226
Oil palm	MY	arable*	-0.079	0.009	0.010	0.010	-0.035	0.013	0.019	0.019
Permanent grass	BR	rangeland	-5.617				-7.002			
	DK	arable	0.090	0.075	0.076	0.078				
	SE	arable/forest					0.857	0.736	0.744	0.740
Rapeseed	DK	arable		0.074	0.076	0.078				
	SE	arable						0.078	0.098	0.097
Rotation grass	DK	arable	0.129	0.108	0.109	0.111				
	SE	arable					0.380	0.326	0.330	0.328
Roughage, maize ensilage	DK	arable	0.357	0.298	0.301	0.308				
	SE	arable					0.342	0.294	0.297	0.295
Soybean	BR	arable*	0.836	0.203	0.229	0.235	0.479	0.140	0.158	0.157
Sugar beet	DK	arable		0.007	0.009	0.009				
	SE	arable						0.003	0.005	0.005
Sunflower	FR	arable		0.092	0.083	0.085				
Wheat cultivation	DK	arable		0.002	0.003	0.003				
	SE	arable					0.066	0.040	0.059	0.058
Total			**-3.61**	**1.08**	**1.18**	**1.21**	**-4.04**	**1.98**	**2.16**	**2.15**

11 Sensitivity analyses

The number of presented sensitivity analyses in this chapter is relatively limited. This is because a considerable share of the uncertainties are already analysed via the different switches for standards and completeness in chapter 10.

11.1 Region of substituted beef system

In the calculated GHG-emissions related to milk, it has been assumed that the substituted beef caused by the meat by-product of the milk system is Brazilian beef. In general the Brazilian beef system is considerably less efficient in terms of land occupation and meat to feed relationship compared to the Danish and Swedish systems. In **section 6.2** the marginal supplier of beef to the global beef market is identified as Brazil. This identification is related to significant uncertainties. Therefore, the following sensitivity analyses show the results where Danish and Swedish beef is substituted instead. **Table 11.1** shows the GHG-emissions related to the production of beef in Denmark, Sweden and Brazil. For Brazil the last column represents a worst case, where Brazilian beef is produced in the Amazon region instead of on rangeland (the Cerrado savannah), hence the affected land tenure market is arable land instead of rangeland. For the ILUC, this significantly affects the results. **Table 11.2** shows the sensitivity analysis, where different beef systems are substituted. The worst case (for Brazilian beef) is not shown, but this would lead to negative results for Danish and Swedish milk, because the substituted beef system is associated with very high levels of GHG-emissions.

Table 11.1: GHG-emissions rela~~e~~ted to the production of beef in Denmark, Sweden and Brazil. The GHG-emissions (kg CO_2-eq.) are shown per 1 kg live weight meat. (Switch: ISO14040/44 consequential).

Contribution	Danish beef (ILUC permanent grass: 100% arable land)	Swedish beef (ILUC permanent grass: 50% arable land, 50% intensive forest land)	Brazilian beef (ILUC permanent grass: 100% rangeland)	Brazilian beef **(worst case)** (ILUC permanent grass: 100% arable land)
Direct emissions (CH_4 and N_2O)	6.78	8.06	9.34	9.34
Feed and other inputs, excl. ILUC	7.82	8.95	6.46	6.75
ILUC related to feed	22.6	20.1	28.1	155
Total	**37.2**	**37.1**	**43.9**	**171**

Table 11.2: Sensitivity analysis for 1 kg ECM milk where different beef systems are substituted. The first column show direct and upstream emissions in the milk system, the second column show the avoided emissions related to the substituted beef system, and the last column show the result for 1 kg ECM. (Switch: ISO14040/44 consequential). Unit: kg CO_2-eq. per 1 kg ECM.

	Milk system and upstream activities	Substituted beef system	GHG-emissions related to 1 kg ECM
Danish milk production			
Danish milk (Brazilian beef substituted)	2.95	-1.88	**1.07**
Danish milk (Danish beef substituted)	2.95	-1.59	**1.36**
Danish milk (Swedish beef substituted)	2.95	-1.58	**1.37**
Swedish milk production			
Swedish milk (Brazilian beef substituted)	3.50	-2.34	**1.16**
Swedish milk (Danish beef substituted)	3.50	-1.98	**1.52**
Swedish milk (Swedish beef substituted)	3.50	-1.98	**1.52**

It appears from **Table 11.2** that the carbon footprint of Danish and Swedish milk is significantly affected by which beef system that is substituted. This uncertainty is only visible in the ISO14040/44 consequential switch mode, since the effects of substituted systems are cut off and ignored by the application of allocation factors in the other switch modes. It should be noticed, that the uncertainty related to the substituted beef system only affects the results for performance tracking and comparison between farms or countries in the case where this implies different outputs of meat per kg ECM. No other changes in the product system will be affected.

11.2 Crop yields

In general, data on crop yields are good. But the contribution to the overall results related to crop yields is significant, and also some crop yields are related to higher uncertainties than other; e.g. yields of permanent grass, rotation grass and maize ensilage are uncertain. Therefore, a sensitivity analysis is carried out, where all yields in the product system of Danish milk are reduced by 25%. The result of the sensitivity analysis is presented in Table 11.3 where the sensitivity analysis is compared with the Danish baseline.

Table 11.3: Sensitivity analysis for 1 kg Danish ECM milk where a scenario where all crop yields are reduced by 25% is compared to the baseline. (Switch: ISO14040/44 consequential).

Contribution	Danish milk baseline		Danish milk 25% reduced crop yields		Explanation of difference
Direct emissions					
CH_4, enteric fermentation	0.548		0.548		No difference
CH_4, manure handling and storage	0.0860		0.0860		
N_2O direct	0.0422		0.0422		
N_2O indirect	0.00647	**0.682**	0.00647	**0.682**	
Emissions outside the animal activities (incl. capital goods and services)					
Feed inputs, excl. ILUC	0.225		0.310		The contribution from the feed and ILUC are higher. No other contributions are affected. The reason why the contribution from feed is higher, is that lower yields means higher loss of nutrients (because fertiliser inputs have not been changed) and subsequent higher emissions of N_2O.
ILUC related to feed	1.95		2.18		
Manure land appl. incl. subst. mineral fert.	-0.0382		-0.0382		
Fuels incl. combustion	0.0142		0.0142		
Electricity	0.0369		0.0369		
Transport	0.0183		0.0183		
Destruction of fallen cattle incl. subst. energy	-0.00435		-0.00435		
Farm, capital goods	0.0271		0.0271		
Farm, services	0.0359	**2.26**	0.0359	**2.58**	
Substituted beef system (incl. capital goods and services)					
Direct emissions (CH_4 and N_2O)	-0.399		-0.399		Only the contribution from ILUC is affected here.
Feed inputs, excl. ILUC	-0.0324		-0.0324		
ILUC related to feed	-1.20		-1.60		
Other	-0.245	**-1.88**	-0.245	**-2.28**	
Total		**1.06**		**0.984**	

It appears from the sensitivity analysis in **Table 11.3** that uncertainties related to crop yields are moderate; a 25% reduction for all crops means an increase in GHG-emissions at 0.22 kg CO_2-eq. in the milk and upstream system and at the same time a reduction at 0.30 kg CO_2-eq. in the substituted beef system. The overall results are not significantly affected because the reduction of yields in the Brazilian beef system (permanent grass) counter balances the increased contributions from lower yields in the Danish milk system (all crops).

11.3 Milk yield

A key parameter for LCA of milk is the milk yield per cow. Therefore, this sensitivity analysis investigates the effects on the results when the milk yield is reduced by 10%. The result of the sensitivity is presented in **Table 11.4**.

Table 11.4: Sensitivity analysis for 1 kg Danish ECM milk where a scenario where the milk yield is reduced by 10% is compared to the baseline. (Switch: ISO14040/44 consequential).

Contribution	Danish milk baseline		Danish milk 10% reduced milk yields		Explanation of difference
Direct emissions					
CH_4, enteric fermentation	0.548		0.566		Generally the emissions increase with lower milk yields. This is because the system becomes less efficient: The feed intake and related emissions per kg ECM for the milking cow remains almost the same, while there is more offspring to be fed per kg ECM.
CH_4, manure handling and storage	0.0860		0.0881		
N_2O direct	0.0422		0.0440		
N_2O indirect	0.00647	**0.682**	0.00671	**0.705**	
Emissions outside the animal activities (incl. capital goods and services)					
Feed inputs, excl. ILUC	0.225		0.156		The contribution from the feed and ILUC increases due to the increased feed requirement by the relative increase in offspring.
ILUC related to feed	1.95		2.18		
Manure land appl. incl. subst. mineral fert.	-0.0382		-0.0393		
Fuels incl. combustion	0.0142		0.0147		
Electricity	0.0369		0.0410		
Transport	0.0183		0.0203		
Destruction of fallen cattle incl. subst. energy	-0.00435		-0.00484		
Farm, capital goods	0.0271		0.0301		
Farm, services	0.0359	**2.26**	0.0399	**2.44**	
Substituted beef system (incl. capital goods and services)					
Direct emissions (CH_4 and N_2O)	-0.399		-0.444		The avoided emissions from the displaced beef system becomes higher because the meat producing offspring has increased compared to milk, i.e. the output of meat from the milk system is higher per kg ECM when milk yields are reduced.
Feed inputs, excl. ILUC	-0.0324		-0.0359		
ILUC related to feed	-1.20		-1.34		
Other	-0.245	**-1.88**	-0.273	**-2.09**	
Total		**1.06**		**1.06**	

The sensitivity analysis shows that the milk yield has very little effect on the overall results. However, the intermediate results change moderately, i.e. the life cycle emissions in the milk system increases while the substituted emissions are reduced accordingly.

It may seem counter intuitive that the milk yields have only minor effect on the results. But the explanation is that the by-product of the milk system; the meat, increases relatively with reduced milk yields. Then the reduced milk efficiency is counter balanced by the substitution of emission intensive Brazilian beef.

11.4 Overall assessment of uncertainties

The overall uncertainties of the Arla model can be divided into some categories in accordance with the purpose of the study: “*Arla wants to estimate and track the development in greenhouse gas (GHG) emission per kg raw milk – both at farm level, national level as well as corporate level which include emissions in several countries.*”

The first category is associated to uncertainties related to the model. 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.

The second category of uncertainties relates to the data inputs to the model. For the national baselines, the most important assumptions relate to the identification of substituted beef system, the animal turnover, the feed composition, and indirect land use changes. The collected data on animal turnover and feed composition in Denmark and Sweden 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 **chapter 11.1**, where it appears that the results are sensitive to the identification of the beef system. This uncertainty cannot be excluded by using other switch modes than the ISO 14040/44 consequential; the uncertainty will then just be invisible and the result will rely on arbitrary assumptions regarding allocation instead of the identification of the substituted system. The uncertainties related to land use changes are also significant. In Schmidt et al. (2012) the major sources of uncertainty are related to the proportion between yield increases and land transformation when the land tenure market is affected, and to the modelling of yield increases which are modelled assuming only additional fertiliser as a flexible mean of increasing yields. Also the data collection in the current study 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 present problems for these switch modes are relevant when the modelling in inventory does not take into account constrained suppliers, when co-product allocation is carried out by use of allocation factors, and when arbitrary cut-off rules are applied. These problems 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 or services leads to incomplete results, and potentially comparisons may be misleading when comparing systems where the emissions from these input categories are different
- The modelling of land use changes in the average/allocation attributional switch mode underestimates the impact, because the attributional scenario in Schmidt et al. (2012) includes constrained supplies of land tenure, 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 the modelling of all indirect changes which are typically included in consequential modelling in LCA. An example is if the milk system in Denmark changed so that only rapeseed meal is used as a source of protein (which is a dependant co-product from rapeseed oil production and thereby it is constrained) and no soybean meal (which is associated with DLUC in PAS2050 and IDF), then some other activities in the market would not be able to have protein feed from the rapeseed meal. These activities will then shift from rapeseed meal to soybean meal, and the net change will be no changes.

12 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.

12.1 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 10**. 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 11.4** 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 use 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 11.4** the most critical uncertainties in data are identified as the ones relating to the 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.

12.2 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%. The effect of omitting capital goods, services and land use changes is investigated in **chapter 10**.

12.3 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 **chapter 3**. 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 7.3). 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.

13 Conclusion

13.1 The carbon footprint tool

The Arla model which is documented in the current study is prepared for the calculation of Danish and Swedish national baselines for milk at the farm gate as well as farm specific carbon footprints. The data inputs to the model for the Danish and Swedish baselines as well as the background data used in the farm specific calculations are documented in a separate inventory report (Dalgaard and Schmidt 2012).

The model is characterised by being parameterised, so that in principle any country or any specific milk farm carbon footprint can be calculated – just by entering the relevant input parameters. Of course there are some limitations in data which are entered as background data in the model, e.g. a milk farm in a country outside EU obviously uses feed inputs with other origins (countries) and maybe also types of feed that is not included in the model. Currently, the model is prepared for country and farm specific carbon footprints for Danish and Swedish milk farms and background data are based on year 2005.

Further, the model enables for applying different modelling assumptions or carbon footprint standards:

- ISO 14040/44 consequential
- Average/allocation attributional
- PAS2050
- IDF guideline

No additional data are required for switching between the above mentioned standards.

It is also possible to operate with different levels of completeness in the results. The following data categories can be switched on and off from any results:

- Capital goods
- Services
- Land use changes

13.2 The baseline results for Danish and Swedish milk 2005

The baseline results for Danish and Swedish milk at farm gate are summarised in **Figure 13.1**.

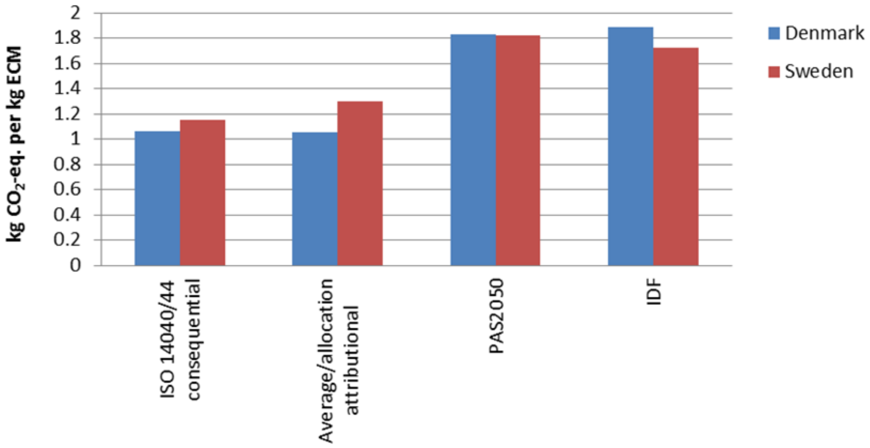

Figure 13.1: Summary of the results; GHG-emissions for 1 kg ECM for the Danish and Swedish baseline.

It appears from the figure, that the results are highly dependent on the choice of modelling switch mode. The major contributions to the overall result include enteric fermentation (methane emissions from the cattle) and the cultivation and production of feed inputs. A major part of the impact related to the feed inputs is associated to land use changes.

13.3 Recommendation regarding modelling approach (switch)

As mentioned in **chapter 13.1** above the model enables for calculating the carbon footprint by use of different modelling assumptions and further different levels of completeness can be switched on and off. Based on **chapter 11.4**, it is recommended to use the ISO 14040/44 consequential switch and the highest level of completeness in results. Hereby, the results represent the likely effect on GHG-emissions relating to a change in demand for milk. No improvement options, uncertainties or assumptions will be invisible and ignored by modelling short cuts. Further, all processes, e.g. the milking cow, will fulfil the mass balance principle.

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