LCA of Dutch semi-skimmed milk and semi-mature cheese

Based on: Comparative LCA of Dutch dairy products and plant-based alternatives

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October 2014

blonk consultants
giving shape to sustainability

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Executive Summary

Purpose
This report is based on the original report (Kramer, Broekema, Tyszler, Durlinger, & Blonk, 2013), which has not been published for third parties. The original report is a Comparative LCA of Dutch dairy products and plant-based alternatives. The LCAs of semi skimmed milk and semi-cured cheese are substracted from the original report and these LCAs are reported as a stand alone study.

FrieslandCampina has requested for this revision because of the recent start of the development of the Product Environmental Footprint (PEF) guidelines by the European Comission and the pilot on dairy products, which is part of the development process. FrieslandCampina wishes to contribute to the development of the PEF for dairy products by sharing this report.

The original report has been reviewed by a panel review. It was a critical review according to ISO 14044 (ISO, 2006) and an independent panel review as stated in the ILCD handbook (JRC-IES, 2010b), as it was a comparative assertion. The review team has agreed to the revision of the original report and does not wish to enter a new review process because of the revision.

The primary goal of this LCA report is to calculate the environmental impact of semi-skimmed milk and semi-marture Gouda cheese, to inform interested parties related to the development of the PEF guidelines by the European Comission and the pilot on dairy products.

Method
The Life Cycle Assessment (LCA) method has been used for determining the potential environmental impacts of semi-skimmed milk and semi-cured cheese. The LCA method is applied in accordance with ISO 14040:2006 and ISO 14044:2006. The functional units of this study are:

- 1 kg of semi-skimmed milk
- 1 kg of semi-cured Gouda cheese

Life cycle inventory data for the dairy farm have been derived from literature and national statistics. Life cycle inventory data for the production of semi-skimmed milk and semi-cured cheese have been derived from FrieslandCampina and are assumed to be representing the Dutch market situation anno 2012. The allocation on the farm is in accordance with the IDF LCA guidance document (IDF, 2010).

Results and Interpretation

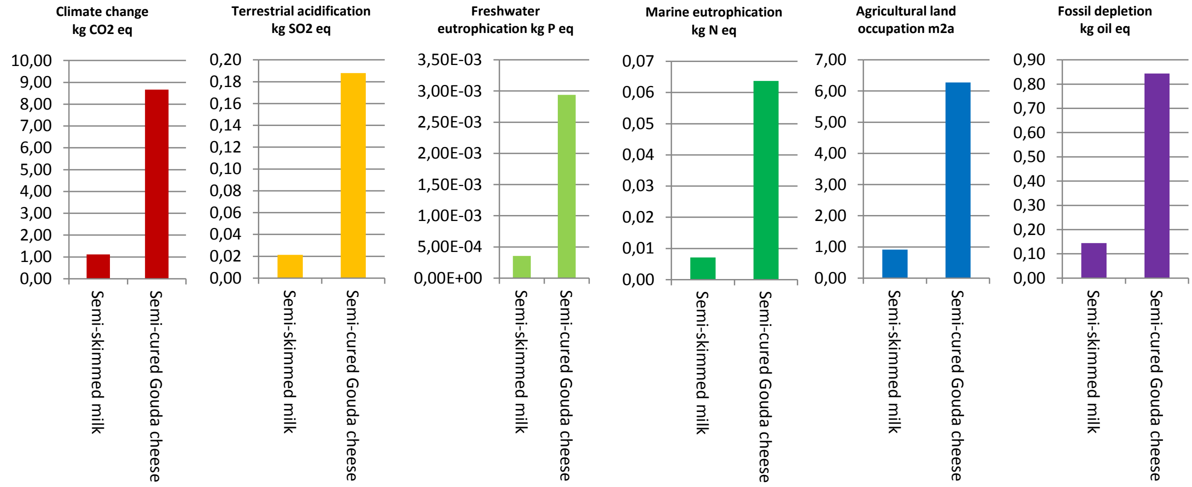

Figure 0-1: Characterised impacts for semi skimmed milk and semi-cured Gouda cheese, impact per kg product.

The results for semi-skimmed milk and semi-cured Gouda cheese are displayed in Figure 0-1, for the following impact categories: climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation and fossil depletion. The contribution of specific lifecycle stage is visualized in chapter 5, and summarized below.

Regarding semi-skimmed milk , for most of the impact categories the dairy farm is the most contributing life cycle stage (75% - 99%). Fossil depletion is the only impact category to which most of the life cycle stages have a considerable contribution, except for the life cycle stage of the production of semi-skimmed milk. The retail stage has a considerable contribution to climate change (~16%), freshwater eutrophication (~10%) as well as fossil depletion (~42%). This contribution is mainly caused by the energy use for cooling and lighting in the distribution centre and the supermarket. Packaging has a considerable contribution to agricultural land occupation (~24%). This is caused by the fact that the packaging is largely made from liquid packaging board which requires trees as a main source of material.

Also regarding semi-cured Gouda cheese, for most of the impact categories the dairy farm stage is the largest contributor. This is not the case for climate change and fossil depletion. These are the impact categories to which most of the life cycle stages have a considerable contribution. Processing, maturation and the retail stage have considerable contributions to climate change (~12%), freshwater eutrophication (~9%) as well as fossil depletion (~43%). This is mostly caused by energy consumption during processing and the energy use for cooling and lighting in the distribution centre and the supermarket. Packaging hardly contributes to the environmental impact.

Enteric fermentation from cattle has a considerable contribution to the impact category climate change of raw milk (~ 35%). Manure, excreted either in the stable or on the pasture, manure application and storage are a second important source. Also the production of feed has a considerable contribution to climate change (see Figure 5-2). The main contributors to terrestrial acidification are emissions of ammonia from manure management and manure application for the cultivation of feed raw materials. Freshwater eutrophication and marine eutrophication are mostly determined by the addition of manure to the soil and both the production and application of synthetic fertilizer for the cultivation of feed ingredients. The cultivation of feed ingredients, especially the processing of feed raw materials for compound feed and by-products, contributes to fossil depletion because of the energy use for field work, processing and transport.

A sensitivity analysis has been performed to test the influence of assumptions on the overall outcomes of the study and an uncertainty analysis has been done to test the robustness of the outcomes. The following assumptions were tested in the sensitivity analysis:

- the additional impact of land use change (not included in the baseline),
- the choice of allocation rules at the farm.

Conclusion and discussion
The main conclusions are:

1. For semi-skimmed milk and semi-cured cheese the impact on climate change ranges from 0.91 to 1.44 kg CO_2eq/kg (1.12 kg CO2eq/kg average) and 6.9 to 11.8 kg CO_2eq/kg (8.67 kg CO2eq/kg average) respectively (95% confidence interval).

2. For semi-skimmed milk and semi-cured cheese the impact on agricultural land occupation ranges from 0.71 to 1.2 m^2a/kg (0.91 m^2a/kg average) and 4.88 to 8.89 m^2a/kg (6.27 m^2a/kg average) respectively (95% confidence interval).

3. For semi-skimmed milk and semi-cured cheese the impact on fossil depletion ranges from 0.12 to 0.18 kg oil eq/kg (0.14 kg oil eq/kg average) and 0.68 to 1.13 kg oil eq/kg (0.84 kg oil eq/kg average) respectively (95% confidence interval).

4. Impacts from land use change are not considered in the baseline scenarios, however if the impact from land use change (LUC) on climate change is included, the impact of both systems increases.
   a. For semi-skimmed milk the impact on climate change increases by 7-21% (depending on the applied method).
   b. For semi-mature cheese, the impact on climate change increases by 8-24% (depending on the applied method).

5. The IDF allocation method was applied for the farm products (raw milk, meat and live animals). If economic allocation would be applied, the impact for semi-skimmed milk would increase (by +/- 5%).

Study limitations

1. The LCI data for production and composition of milk and cheese were obtained from a limited amount of producers, but with a significant market share. We assume that these are representative for similar products available on the Dutch market.

2. LUC is not part of the main report, but only explored in the sensitivity analysis for the dairy products and the main substitutes.

3. Capital goods were not included in processes related to crop cultivation and processing, but they were included in background processes (for example, related to transport and energy production). The environmental impacts would increase if capital equipment were to be included consistently for all lifecycle stages.

4. No impact category on midpoint level dealing with water/water scarcity was analysed. Some of the analysed products were cultivated in water scarce areas.

Contents

Glossary

Term	Definition
Agri-footprint	Database with carbon footprints for Dutch feed ingredients
CBS	*Centraal burea voor statistiek* Dutch national statistics agency
CI	Confidence interval
CV	Coefficient of variation
Ecoinvent	Swiss life cycle inventory database
EVOH	Ethylene vinyl alcohol, a type of plastic
FAO	Food and Agriculture organisation of the United Nations
FU	Functional Unit
GHG	Greenhouse gas
HDPE	High Density PolyEthylene, a type of plastic
HFCS	High Fructose Corn Syrup
IDF	International Dairy Federation
ILCD	International Reference Life Cycle Data System
KWIN	*Kwalitatieve Informatie* Source of qualitative information on various agricultural processes and systems
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LU	Land Use
LUC	Land use change
NEVO	Dutch Food Composition Database
NIR	National Inventory Report
NOx	Oxides of nitrogen
PAS 2050	Carbon foot printing standard
PAS 2050:2012-1	Specification for the Dutch horticultural sector based on PAS 2050
PCR	Product category rules
PDV	Dutch Product Board Animal Feed
ReCiPe	Life cycle impact assessment method developed by a consortium of Dutch companies and universities
SOx	Oxides of sulphur
USDA	United States Department of Agriculture
WHO	World Health Organisation

1 Introduction

1.1 Context and background

This report is based on the original report (Kramer et al., 2013), which has not been published for third parties. The original report is a Comparative LCA of Dutch dairy products and plant-based alternatives. For the original study FrieslandCampina asked Blonk Consultants to compare the environmental impact of semi-skimmed milk and semi-mature Gouda cheese with some suggested alternatives mentioned by the Dutch Nutrition Center taking into account the differences in nutrient content. This report only presents the LCA of semi-skimmed milk and semi-cured cheese. No changes have been made in the LCA except for choosing the IDF allocation on farm level as the baseline method, instead of economic allocation.

FrieslandCampina has requested for this revision because of the testing of the Product Environmental Footprint (PEF) guidelines by the European Comission and the pilot on dairy products, which is one of 11 pilots on food products. FrieslandCampina wishes to contribute to the development of the PEF for dairy products by sharing this report with the technical secretariat of the dairy pilot.

The original report has been reviewed by a panel review. It was a critical review according to ISO 14044 (ISO, 2006) and an independent panel review as stated in the ILCD handbook (JRC-IES, 2010b), as it was a comparative assertion. The review team has agreed to the revision of the original report and did not wish to enter a new review process because of the revision.

1.2 Life Cycle Assessment

Life Cycle Assessment (LCA) was used as the core method for determining the potential environmental impacts of the products considered. The LCA methodology has been applied in accordance with ISO 14040:2006 and ISO 14044:2006.

LCA is a method for evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle. Figure 1-1 illustrates the life cycle system concept, i.e. natural resources and energy entering the system are converted into products resulting in generation of waste and emissions leaving the system.

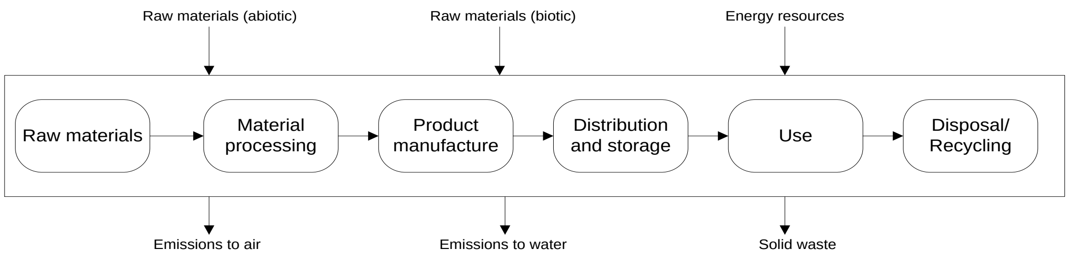

Figure 1-1: Life cycle system concept

The International Standards Organization defines LCA as the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a production system throughout its lifecycle (ISO 14040:2006). The LCA framework consists of four project stages; goal and scope definition, inventory analysis, impact assessment and interpretation (Figure 1-2).

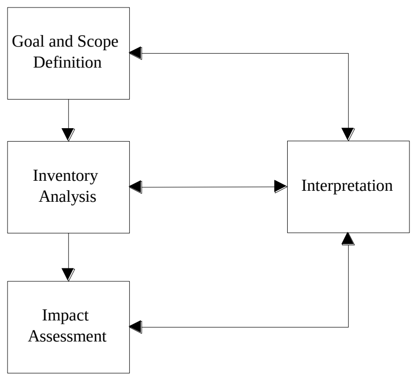

Figure 1-2: The components of an LCA (ISO, 2006)

1.3 Involved parties

Execution of this project involved three main parties. The first party, FrieslandCampina was the commissioner of the project, who wished to gain insight into environmental aspects of some of their main dairy products. The second party, Blonk Consultants was the company requested by FrieslandCampina to perform the analysis. The third party was a team of reviewers performing a critical review of the (original) study according to ISO 14044 guidelines (ISO, 2006).

1.3.1 LCA commissioner: FrieslandCampina

FrieslandCampina is one of the world's largest dairy co-operatives (FrieslandCampina, n.d.), with 15.300 member farmers in the Netherlands, Belgium and Germany. FrieslandCampina produces fresh dairy, cheese, dairy based ingredients and beverages.

1.3.2 LCA practitioner: Blonk Consultants

Blonk Consultants helps companies, governments and civil society organisations to put sustainability into practice. Blonk Consultants has a broad experience in analysing and giving insight into the environmental impact of agricultural produce and is regarded as an important source of data by scientists and stakeholders. Recently performed studies dealt with cheese (Marinussen, Kool, & Blonk, 2011), pork (Kool et al., 2010), chicken (Blonk, Ponsioen, Kool, & Marinussen, 2011) and a comprehensive database of animal feed ingredients (Vellinga et al., 2013). In the latter soy cultivation and processing were analysed in detail.

1.3.3 Reviewers

A team of reviewers was selected. The chairman of the team was Dr. Jannick H. Schmidt from 2.-0 Consultants and Aalborg University. He has selected Dr. Fausto Freire from the University of Coimbra, Dr. Toni Meier from the Martin Luther University of Halle-Wittenberg and Prof. Dr. ir. Imke de Boer of Wageningen UR to perform the critical review. Blonk Consultants and FrieslandCampina suggested some of the candidates.

2 Goal and Scope definition

2.1 Goal of the study

The primary goal of the analysis is to calculate the environmental impact of semi-skimmed milk and semi-marture Gouda cheese, to inform interested parties related to the development of the PEF guidelines by the European Comission and the pilot on dairy products.

2.1.1 Reasons for carrying out this study

The study will give interested parties insight into the environmental impact of 2 important dairy products as produced in the Netherlands.
Improvement analysis of dairy products is not a main goal in this analysis, but is discussed briefly based on the processes in the production chain that have a major impact on the environment.

2.1.2 Intended audience

This report is intended to be used in the development of the PEF guidelines by the European Comission and the PEF pilot on dairy products, which is part of the development process.

2.1.3 Critical review process

Because the original study was a comparative assertion a panel review has been established in accordance with the original goal of the study, as it was a comparative assertion that may be disclosed to the public. More specifically, it was a critical review according to ISO 14044 (ISO, 2006) and an independent panel review as stated in the ILCD handbook (JRC-IES, 2010b). The review process was an interactive process through the various stages in the LCA. The steps include:

1. Review of the Goal & Scope
2. Consultation step, if required, for instance when issues arise regarding data quality, assumptions, accounting land use change (LUC) and availability of data
3. Review of the final report

The review process is documented in Appendix A. The final review statement from the review panel is added in Appendix B and the response to the review comments is listed in Appendix C. The points which do not apply to the revision of the original report have been deleted.

The review team has agreed to the revision of the original report and do not wish to enter a new review process because of the revision.

2.2 Scope of the study

2.2.1 General description of the systems in scope

Semi-skimmed milk and cheese from FrieslandCampina are primarily based on raw milk collected from Dutch farms from the co-operative. The milk is transported to the processing facilities, where it is defatted to a standardized fat-content for the desired product. To produce semi-skimmed milk the standardized raw milk is subsequently pasteurized and packed. Cheese is made by adding rennet and specific bacterial cultures to milk with a standardized amount of fat. This causes clotting of proteins, which separates the fresh cheese (curd) from the fluid (whey). The fresh cheese is then stored in brine baths for a few days. Afterwards the cheeses are coated and stored on shelves to mature.

Raw milk is produced at dairy farms across the Netherlands. Dairy cows producing milk also produce calves and meat after they are slaughtered. The cattle are fed corn silage, grass silage, fresh grass and compound feed. This study includes the impacts associated with production of the feed ingredients and feed processing, as well as the impacts associated with the use of raw materials and emissions into the environment at the farm and elsewhere (up- and downstream) in the chain, including N- and P-balances that take all inputs and uptake of crops into account.

2.2.2 Systems functions

The primary function of food and drinks is to provide energy, macro- and micronutrients and water to sustain human life. Apart from that, they give pleasure and satisfaction. For consumer choice, the latter functions might even be more determining. Food patterns and food habits vary within and across nations and regions, and are part of the cultural heritage of countries. Traditionally, dairy products, like milk and cheese, are an important part of Dutch food culture and diet.

2.2.3 Functional unit

The functional units of this study are:

- 1 kg packed semi-skimmed milk
- 1 kg packed semi-cured Gouda cheese

2.2.4 Software tools

SimaPro 7.3.3 LCA software and Blonk Consultants' Agri-footprint LCA software were used as tools to calculate and analyse the environmental impact.

The LUC emissions (see section 5.4.1) were calculated using the LUC calculation tool that was developed alongside the PAS2050-1 and is under further active development at Blonk Consultants. Version 2.4 of the tool was used for this report; the latest version can currently be found via the website of Blonk Consultants.

2.2.5 Reference flows

For this analysis the functional unit is represented by an equal reference flow:

- 1 kg of packed semi-skimmed milk
- 1 kg of packed semi-cured Gouda cheese

2.2.6 System boundaries

The life cycle of the semi-skimmed milk and semi-mature Gouda cheese produced by FrieslandCampina is shown in Figure 2-1 and Figure 2-2. The average Dutch milk, being milk from an average Dutch farm, is analysed and not milk from the Dutch dairy sector as a whole. The system boundaries were cradle-to-grave for all products in scope, including upstream emissions associated with feed production. Capital goods were excluded, which is common practice in many current product category rules (PCR) of processed agricultural products because they generally contribute far less than 5% to the impact (see 2.2.7). Consumer transport from supermarket to the use was omitted, because this life cycle stage is identical for all products in scope. Also sewage treatment of human excretion was left out, because of its small contribution to the overall impact (Muñoz, Milà i Canals, & Fernández-Alba, 2010). Waste incineration with energy recovery was assumed as the basic end-of-life scenario in the Netherlands for food spoilage and packaging.

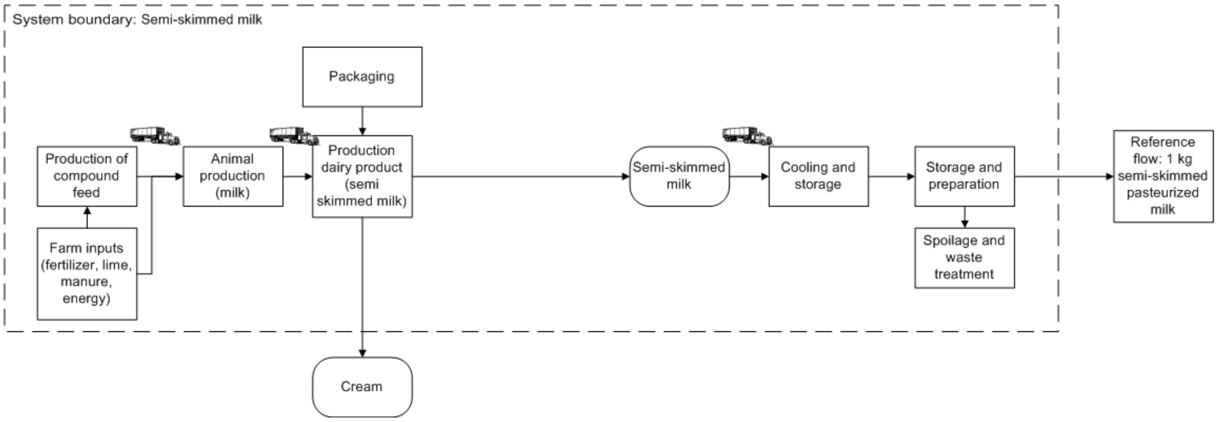

Figure 2-1: Process diagram of the current life cycle of semi-skimmed milk. The system boundary is depicted by a dotted line. Product flows are represented by arrows. Processes are represented by 'square' boxes while products are depicted by boxes with rounded edges. The reference flow is shown on the right hand side of the figure. Transport steps are depicted by small trucks. Virtually all processes use energy and water which are included in system boundary. Some products (Cream, Soy bean hulls and Soy pulp), are outside the system boundaries and therefore allocation has taken place in the preceding multi-output process.

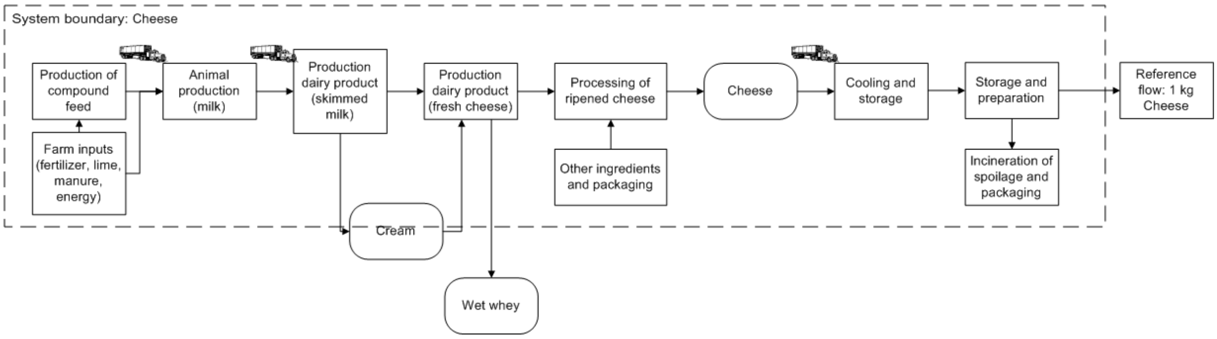

Figure 2-2: Process diagram of the current life cycle of cheese. The system boundary is depicted by a dotted line. Product flows are represented by arrows. Processes are represented by 'square' boxes while products are depicted by boxes with rounded edges. The reference flow is shown on the right hand side of the figure. Transport steps are depicted by small trucks. Virtually all processes use energy and water which are included in system boundary. Some products (Whey, Rapeseed meal, sugar beet molasses), are outside the system boundaries and therefore allocation has taken place in the preceding multi-output process. In cheese making, part of the cream produced dairy processing is used in the cheese making process and part is co-product, therefore the product lies partly inside and partly outside the system boundary.

2.2.7 Cut-off criteria

The cut-off criteria for the inclusion of inputs and outputs were based on mass and energy. Foreground energy and mass flows (associated directly with dairy production and the plant based equivalents) used in the impact assessment methods were captured, however, some background flows associated with the background datasets (energy production, transport, fertilizers etc.) may have been omitted. It is estimated that elementary flows representing not more than 5% of the cumulative mass and energy flows were omitted, including emissions associated with management of waste produced. These cut-off criteria are considered not to influence the directional outcomes of this study.

We attempted to be complete within the system boundaries. We did not, however, correct for intentionally omitted processes, such as capital goods of industries and the production and use of pesticides (see 2.2.12). A study by Frischknecht et al (2007) suggests that in agricultural processes capital goods may have a large impact on certain impact categories (particularly mineral depletion and to a lesser extent toxicity related impacts). However these impact categories are not considered in this study, therefore the exclusion of these capital goods is considered not to affect the studies outcomes and below the cut-off percentage.

2.2.8 Allocation rules

The LCA followed an attributional or accounting approach, where the LCI modelling framework inventories the input and output flows of all processes of the systems in scope as they occur (ILCD, 2010). According to the ILCD Handbook, provision 6.5.4, allocation shall be avoided by substitution (this applies to decision context: Micro-level decision support which is relevant for the current study).

Avoiding allocation by substitution (system expansion) could and has been applied for only a limited number of cases. In the treatment of wastes through incineration, heat and electricity are co-produced. In this case it is assumed that electricity from incineration displaces the Dutch average electricity mix, the generated heat is used in heating of offices or in district heating and displaces heat from a gas boiler.

However, consistently applying system expansion would be highly complex in the case of dairy feed production, where we have to deal with a large number of co-products. This is also applicable to dairy processing. Particularly in feed materials for dairy farms, a lot of co-products from food production are utilised, and mostly those co-products do not have single substitutes, so substutition concerns a mix of products that are quite often again co-products themselves. A related issue is that these substitutes have not been clearly identified in the life cycle data available for this study, and therefore it will be very time consuming to employ a full system expansion approach for this study and questionable if all the required data is even available (as we need to identify and model the displaced products, and the products that the co-products of the displaced product would have displaced etc.)[1].

The ILCD guide mentions that multi-functionality may be solved by allocation in case of high complexity (ILCD general guide p82), and we think that this criterion is applicable here (due to complexity and unavailability of data). So, in this study we applied economic allocation except for processes where energy is produced and supplied to a grid as explained above and for manure application as explained at the end of this section. Data on feed was allocated on an economic basis as is described in the methodology report of the feed studies that were used as a basis for feed LCIs in this study (Vellinga et al., 2013). The dairy

[1] The costs to do a full system expansion LCA exceeds the budget, moreover we foresee some discussions on replacement options. Also, some LCA practitioners regard system expansion as a consequential approach to allocation, and that producer specific co-product substitutions need to be known, to be able to apply system expansion in a attributional context (WRI-WBCSD & WBCSD, 2011).

products semi-skimmed milk and cheese were allocated based on physical composition of the co-products and their economic value; i.e. the protein, fat and lactose content and their respective price.

For the dairy farm phase, allocation according to the International Dairy Federation's (IDF) standard for carbon footprinting (IDF, 2010) was used. This standard uses a biophysical allocation method based on the energy requirement of the animal to produce milk and meat. Also for allocation of the inputs and outputs of a manufacturing site it uses physico-chemical allocation if only "whole of factory data" are available, but this was not the case in this study because detailed processing data were available. Economic allocation for the dairy farm phase is included in the sensitivity analysis to assess the impact of an alternative allocation method on the LCA outcomes.

The manure which is produced on the dairy farm is applied to the soil on the dairy farm for grass and corn cultivation. Generally though, the dairy farm could have excess manure which is removed from the farm to be applied to the soil for crop cultivation by someone else, this removed manure does not provide revenue for the farmer (and economic allocation is therefore not feasible). For nitrogen and phosphorous in manure that is removed from the farm to be applied to the soil by someone else, a cut-off rule has been applied. This means that the emissions due to application of the manure that is removed from the farm are allocated to the next crop system for 100%. This rule is applied for the application of manure for the cultivation of feed raw materials as well as for the manure removed from the dairy farm.

2.2.9 Data collection procedures

The inventory analysis was done partly by FrieslandCampina and partly by Blonk Consultants. Blonk Consultants made a data request to guide FrieslandCampina in the data collection process for the dairy products in scope. For background inventory data, Ecoinvent version 2.2 (for fertilizer production, energy and transport processes), Blonk Consultants' Agri-footprint database (feed and food crop cultivation, and processing into feed and food products) and scientific literature were used.

Blonk Consultants also collected data on feed compositions used by dairy Dutch farmers, the farming system, soil type, manure management and prices. Data on feed raw materials were taken from Feedprint (Vellinga et al., 2013) and suppliers. FrieslandCampina provided data on processing and transport. The impact of variation of these data was explored in the uncertainty analysis.

End of life inventory data were based on the most recent data available for incineration in Europe. Data on cooling in supermarkets was obtained from the largest supermarket chain in the Netherlands.

Uncertainty data were collected as part of the inventory. If specific data (variation and distribution type) on uncertainty were available we used them. Otherwise we used a standardized table (Pedigree matrix) with uncertainties per process/activity that we have derived from literature and expanded on in the Feedprint methodology (Vellinga et al., 2013). See section 5.5.1 for details about the uncertainty analysis.

2.2.10 Key assumptions

The LCI data for production and composition of milk and cheese was obtained from FrieslandCampina. We assume that these are representative for similar products available on the Dutch market. Uncertainty in data related to this assumption is part of the uncertainty analysis.

The amount of spoilage per product category in the consumer phase was estimated based on a representative survey from 2010 (Van Westerhoven & Steenhuizen, 2010). However, recently the same agency reported an average increase of 68% spoilage relative to the 2010 study (CREM, 2013) we did not account for this, because no further details were available on dairy products at that time.

2.2.11 Data quality requirements

Table 2-1 lists the data quality requirements for some key processes. For the processes that form the core of this study, very specific data is required. The categories for data quality requirements are derived from the ISO14044:2006 standard. In section 5.7, it is evaluated how well the data used in this study fulfils these requirements.

Table 2-1: Data quality requirements.

Data Description	Time related coverage	Geographical coverage	Technology Coverage	Precision	Completeness	Representativeness	Consistency	Primary sources of Data	Uncertainty	Type of data required
Dairy cow ration composition	After 2010	Netherlands	Technology Mix	Representative for Dutch average	>95%	Dutch average	Consistent with study methodology	Literature and statistics	Average	Feed quantities
Feed cultivation and processing	After 2010	Netherlands and imports from Europe and rest of the world.	Technology Mix	Representative for Dutch average	>95%	Dutch average	Consistent with study methodology	Literature and statistics	Average	Process and environmental flows
Dairy farm processes	After 2010	Netherlands	Technology Mix	Representative for Dutch average Good	>95%	Dutch average	Consistent with study methodology	Literature and statistics	Average	Process and environmental flows
Energy supply	After 2005	Netherlands plus imports	Technology Mix	Representative for Dutch average	>95%	Dutch average	Consistent with study methodology	Background dataset	Average	Process and environmental flows
Milk manufacturing processes	After 2005	Netherlands	Technology Mix	Specific to manufacturer process	>95%	FrieslandCampina's processes	Consistent with study methodology	Manufacturer data	Average	Process and environmental flows
Cheese manufacturing processes	After 2005	Netherlands	Technology Mix	Specific to manufacturer process	>95%	FrieslandCampina's processes	Consistent with study methodology	Manufacturer data	Average	Process and environmental flows
Packaging	After 2005	Europe	Technology Mix	Representative for variability in packaging production	>95%	For specific products	Consistent with study methodology	Manufacturer/ Background data	Average	Material quantities, process and environmental flows

2.2.12 Life cycle impact assessment method

The LCIA methods cover the midpoints mentioned in Table 2-2, calculated according to the ReCiPe method at midpoint level (hierarchy, version 1.06, European normalization) (Goedkoop et al., 2013).

Pesticides, and their impact on certain midpoints, were not taken into account in this study due to the limited availability of data, the high variability in pesticide use in countries of origin, while even the origin of crops is very unsure (n.b. Ecoinvent only lists a small number of pesticides, and there is poor data on pesticide use during growing of feed ingredients and other crops, while the toxicity of pesticides varies widely).

Some impact categories were excluded (ozone depletion, toxicity categories, photochemical oxidant formation, particulate matter, ionising radiation, urban land occupation, water and metal depletion) for two interrelated reasons:

1. Wish of the commissioner. The impact categories to be included were discussed with the commissioner of the study at the start of the project, resulting in the list of Table 2-2.
2. A lack of primary data of sufficient quality. This was mainly the case for the toxicity categories. Due to a lack of pesticides application rates on crops, there was a significant data gap that could not be fixed. Reporting on toxicity would therefore give a unreliable outcome. Similar data gaps were found for the other excluded impact categories, that could potentially be overcome, but as the commissioner was mainly interested in other impact categories no effort was made to support these categories.

Table 2-2: Impact assessment indicators.

Midpoint impact category	Description	Unit
Climate change	The contribution to climate change by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other greenhouse gases	kg CO_2 eq.
Terrestrial acidification	Contribution to the acidification of the soil by for instance deposition of ammonia and other acid substances	kg SO_2 eq.
Fresh water eutrophication	Contribution to the eutrophication of fresh water by the leaching/emission of nutrients as nitrogen and phosphorus	kg P eq.
Marine eutrophication	Contribution to the eutrophication of marine (sea) water by the leaching/emission of nutrients as nitrogen and phosphorus	kg N eq.
Agricultural Land occupation	The use of agricultural land	m^2 * year
Natural Land Transformation	The change of natural land into non-natural land as agricultural or urban	m^2
Fossil depletion	Use of fossil energy sources	kg oil eq.

2.2.12.1 Land use change

Following an attributional approach, only Land Use Change[2] (LUC) as a result of current land use was calculated (and indirect effects were not assessed), and reported separately since there is no consensus on a preferred method yet. LUC has most importantly an impact on climate change, but can also, among others, affect biodiversity and soil quality. LUC was not calculated in the base analysis, but was part of the

[2] For the cultivation of some crops land use is changed for instance from forest to cropland, from grassland to cropland or between perennial and annual crops. This shift in land use (land transformation) causes a long term impact on climate change.

sensitivity analysis (5.4.1). In the sensitivity analysis, only the impact category of climate change is taken into account.

In line with the study goals, we selected LUC methods that fit into an attributional approach. The following methods have been evaluated in the selection of a LUC method and the results are presented in the sensitivity analysis taking into account if they are recommended in LCA standards, PCRs or other LCA reference documents and practicality (available model and characterization factors):

1. PAS 2050:2012-1(BSI, 2012)
2. UNEP SETAC (Milà i Canals, Rigarlsford, & Sim, 2012)
3. Top down approach (Audsley et al., 2009, Vellinga et al., 2013)

The PAS 2050:2012-1 and UNEP SETAC method both calculate the emissions associated with land transformation for the previous 20 years. The UNEP SETAC method uses the climate regulation potential (Müller-Wenk & Brandão, 2010), which is based on the Bern carbon cycle and the lifetime of LUC related carbon in the atmosphere. The method proposed by Audsley et al.(2009) and later on applied by Vellinga et al.(2013) (here called the Top down approach) avoids the uncertainty due to time and regional allocation and is based on a single global LUC emission factor per unit land occupation.

A short explanation is given of each methodology:

PAS 2050:2012-1: The method is based on allocating a historical one time release of biogenic carbon due to land transformation to current land occupation. It allows for differentiation based on climatic condition, soil type and countries. The Bern Cycle of Carbon in the atmosphere is not taken into account. The most crucial assumption in this method is the 20 year depreciation period. Another debatable assumption is the methodology to derive an average land transformation in a country (if specific location and history of land transformation are unknown). Furthermore, some IPCC default values do not give an accurate estimation on a country level, so uncertainty of results is strongly correlated with information available about the location where the land transformation occurs.

UNEP-SETAC: In this method there is a distinction between the land occupation impact and land transformation impact. Developed within the framework of the UNEP/SETAC Life Cycle Initiative, the study focuses on the climatic impact of land use as determined by the transfers of CO_2 between vegetation/soil and the atmosphere in the course of terrestrial release and re-storage of carbon. It uses the Bern Cycle of Carbon to calculate the mean lifetime of CO_2 in the air due to LUC and is expressed as 'fossil-combustion-equivalent' (tons of carbon) so that they are expressed in the usual LCA indicator for global warming potential. The regeneration capacity of the biome (currently it is confined to types of forest and grassland) to take up the CO_2 emitted during the transformation is taken into account with a cut-off limit of 500 years. The methodology to derive average land transformation is the same as used in the PAS2050-1, and the emissions provided by Müller-Wenk & Brandão are applied.

Top down Approach: This method was developed by Audsley et al. (Audsley et al., 2009) to allocate GHG emissions of current global land transformation to current consumption of crops in countries. Vellinga *et al.* (Vellinga et al., 2013) applied the method to allocate global land use change GHG emissions to consumption of feed crops. The method is part of the Feedprint tool which is adopted by FEFAC as the starting point for making GHG assessments of animal feed. It does not apply any allocation to causes and locations, so it does not imply any specific assumptions on the transformation mechanism. The main assumption is that land is a global commodity that is consumed in response to a global demand. This approach does not distinguish between expanding crops due to new developments and crops that don't expand.

All three methods have a different approach to calculating the impact of LUC on climate change. PAS2050 recommends allocating the impact on a yearly basis (equal to $1/20^{th}$ of the total area converted in the past 20 years) while UNEP/SETAC allocates all the the transferred area in the past 20 years to the product system. Hence, even though in the UNEP/SETAC method the characterization factor as such is relatively low (due to the assumptions regarding regeneration time), allocating all the impact at once causes the highest outcomes. In case of the top down approach, the total GHG emission due to LUC is calculated for the product system on the basis of distributing the global average LUC GHG per hectare of agriculture land. There is no consensus on the best method to calculate climate change induced by LUC, which is why the impact of LUC is reported separately. Al three methods have been selected to calculate the contribution of LUC to climate change in the sensitivity analysis (Chapter 5.4.1).

2.3 IPCC emission factors and calculation rules

The IPCC guidelines (IPCC, 2006a, 2006b, 2006c) were used for the calculation of the environmental impact of plant- and animal production systems in this analysis. An exception is the emission due to enteric fermentation, which were based on emission factors of the Dutch NIR (CBS, WUR, RIVM, & PBL, 2011) as mentioned in 3.1.2, although the Dutch NIR uses the Tier 3 IPCC method each year for calculating enteric fermentation for dairy.

A choice has been made for IPCC guidelines. Other guidelines like the NIR might use other emission factors, which might have an impact on for instance GHG emissions due to fertilizer application or GHG emissions due to use of peat lands. The impact of using other guidelines has not been investigated.

2.3.1 Plant production system and manure management

In the plant production system there are emissions of dinitrogen monoxide (N_2O), ammonia (NH_3) and leaching of nitrate (NO_3^-) to the ground and surface water due to the application of synthetic and organic N-fertilizer/ manure, urea and crop residues and emissions of carbon dioxide (CO_2) due to application of lime fertilizer. There are also emissions of phosphorous to the soil due to the application of P_2O_5-fertilizer. The calculation rules for quantifying these emissions are displayed in Equation 2-1 to Equation 2-12.

Equation 2-1 Direct emission of N_2O due to the application of N-fertilizer

$$\text{kg } N_2O = [\text{kg N from N-fertilizer}] * 0.01 * (44/28)$$

$$\text{kg } N_2O = [\text{kg N from manure}] * 0.02 * (44/28)$$

Equation 2-2 Indirect emission of N_2O due to volatilization of NH_3 resulting from application of N-fertilizer

$$kg\ N_2O = [\text{kg N from N-fertilizer}] * 0.1 * 0.01 * (44/28)$$

$$kg\ N_2O = [\text{kg N from other N source}] * 0.2 * 0.01 * (44/28)$$

Equation 2-3 Indirect emission of N_2O due to leaching of NO_3^- resulting from application of N-fertilizer

$$kg\ N_2O = [\text{kg N from N-fertilizer}] * 0.3 * 0.0075 * (44/28)$$

Equation 2-4 Direct emission of N_2O due to crop residues

$$kg\ N_2O = [\text{kg N from crop residues}] * 0.01 * (44/28)$$

Equation 2-5 Indirect emission of N_2O due to volatilization of NH_3 resulting from crop residues

$$kg\ N_2O = [\text{kg N from crop residues}] * 0.2 * 0.01 * (44/28)$$

Equation 2-6 Indirect emission of N_2O due to leaching of NO_3 resulting from crop residues

kg N_2O = [kg N from crop residues] * 0.3 * 0.0075 * (44/28)

The amount of N from crop residues is calculated according to the calculation rules and default factors in IPCC, Vol.4, chapter 11, equation 11.7A and table 11.2 (IPCC, 2006c).

Equation 2-7 Emission of NH_3 due to the application of N-fertilizer

kg NH_3 = [kg N from N-fertilizer] * 0.1 * (17/14)

kg NH_3 = [kg N from other N source] * 0.2 * (17/14)

Equation 2-8 Emission of NH_3 due to crop residues

kg NH_3 = [kg N from crop residues] * 0.2 * (17/14)

Equation 2-9 Leaching of NO_3^- due to the application of N-fertilizer

kg NO_3^- = [kg N from N-fertilizer] * 0.3 * (62/14)

Equation 2-10 Leaching of NO_3^- due to crop residues

kg NO_3^- = [kg N from crop residues] * 0.3 * (62/14)

Equation 2-11 Emission of CO_2 due to the application of lime fertilizer

kg CO_2 = [kg lime] * 0.44

Equation 2-12 Emission to soil of P due to the application of P-fertilizer

kg P = [kg P_2O_5 from fertilizer] * (62/142)

2.3.2 Animal production system

In the animal production system there are emissions of dinitrogen monoxide (N_2O), ammonia (NH_3) and leaching of nitrate (NO_3^-) to the ground water due to the application of manure. Emission of phosphorous to the soil also occurs due to the application of manure. The excretion of manure in the pasture results in emissions of dinitrogen monoxide (N_2O), ammonia (NH_3) and biogenic methane[3] (CH_4), leaching of nitrate (NO_3^-) and deposition phosphorous. The excretion of manure in the stable results in emissions of dinitrogen monoxide (N_2O), ammonia (NH_3) and biogenic methane (CH_4). The animals on the farm emit biogenic methane (CH_4) due to enteric fermentation (mainly emitted through belching but also passed out as flatulence). Finally dairy farms in the Netherlands can be located (partly) on peat lands, which involves emissions of carbon dioxide (CO_2) and dinitrogen monoxide (N_2O).

Equation 2-13 Direct emission of N_2O due to the application of manure

kg N_2O = [kg N from manure storage] * 0.02 * (44/28)

Equation 2-14 Indirect emission of N_2O due to volatilization of NH_3 resulting from application of manure

kg N_2O = [kg N from manure storage] * 0.2 * 0.01 * (44/28)

Equation 2-15 Indirect emission of N_2O due to leaching of NO_3^- resulting from application of manure

[3] The GWP100 of biogenic methane 22.25 kg CO_2eq./kg CH_4 is used if captured biogenic carbon is emitted as methane within 100 years after capture. See Muñoz, Rigarlsford, Milà i Canals, & King (2012) for rationale.

kg N_2O = [kg N from manure storage] * 0.3 * 0.0075 * (44/28)

Equation 2-16 Emission of NH_3 due to the application of manure

kg NH_3 = [kg N from manure storage] * 0.2 * (17/14)

Equation 2-17 Leaching of NO_3^- due to the application of manure

kg NO_3^- = [kg N from N-manure storage] * 0.3 * (62/14)

Equation 2-18 Emission to soil of P due to the application of manure

kg P = [kg P from manure]

The emissions of N_2O, NH_3, NO_3^- and P were calculated in the same way for the excretion of manure on the pasture as for the application of manure on the pasture. On top of these emissions the excretion of manure on the pasture also results in emission of biogenic methane (CH_4).

Equation 2-19 Emission of CH_4 due to excretion of manure in the pasture (kg CH_4/animal/year)

kg CH_4 = (5.1 * 365) * 0.24 * 0.01 * 0.662

Equation 2-20 Direct emission of N_2O due to excretion of manure in the stable

kg N_2O = [kg N from N-manure] * 0.002 * (44/28)

Equation 2-21 Indirect emission of N_2O due to excretion of manure in the stable

kg N_2O = [kg N from N-manure] * 0.28 * 0.01 * (44/28)

Equation 2-22 Emission of NH_3 due to excretion of manure in the stable

kg NH_3 = [kg N from N-manure] * 0.28 * (17/14)

Equation 2-23 Emission of CH_4 due to excretion of manure in the stable (kg CH_4/animal/year)

kg CH_4 = (5.1 * 365) * 0.24 * 0.17 * 0.662

Equation 2-24 Emission of CO_2 due to the use of peat land (kg CO_2/farm/year)

kg CO_2 = [ha peat land on the farm] * 917

Equation 2-25 Emission of N_2O due to the use of peat land (kg N_2O/farm/year)

kg N_2O = [ha peat land on the farm] * 8

3 Life Cycle Inventory

Most of the information is derived from literature sources and national statistics. If no literature could be found, missing data were calculated or estimated. The general background database, if data could not be found, was the Ecoinvent database version 2.2. The following section describes the products that make up the reference flows semi-skimmed milk (3.1) and semi-cured Gouda cheese (3.2), including the feed cultivation and processing in the Netherlands for the production of raw milk, semi-skimmed milk and semi-mature Gouda cheese. Section 3.3 presents the inputs for the retail, consumer and waste treatment phase of the systems under consideration.

3.1 1 kg semi-skimmed pasteurized milk

3.1.1 Feed cultivation and processing

3.1.1.1 Concentrates, protein rich feeds and wet by-products

In 2010 and 2011 a study was performed for the Dutch Product Board Animal Feed (PDV) by Wageningen University and Blonk Consultants in which life cycle inventories (LCIs) were developed for the cultivation of crops used in compound feeds. Also LCIs of the corresponding processing of these crops to feed materials were developed. The following reports contain the feed LCIs[4]:

Cultivation:

- Legumes (Marinussen et al., 2012b)
- Oil seeds and oil fruits (Marinussen et al., 2012e)
- Forage and roughage (Vellinga, Boer, & Marinussen, 2012)
- Cereal grains (Marinussen et al., 2012a)
- Roots and tubers (Marinussen et al., 2012f)
- Other seeds and fruits (Marinussen et al., 2012d)
- Other plants (Marinussen et al., 2012c)
- Animal products (van Zeist et al., 2012a)

Processing:

- Crushing industry (van Zeist et al., 2012c)
- Wet milling industry (van Zeist et al., 2012g)
- Sugar industry (van Zeist et al., 2012f)
- Ethanol industry (van Zeist et al., 2012b)
- Dry milling industry (van Zeist et al., 2012d)
- Other processing (van Zeist et al., 2012e)

The LCIs were developed to be used for carbon footprints. Pesticide use as a source for GHG emission was not taken into account in the above LCIs due to the limited data quality of LCI datasets and the high variability in pesticide use in countries of origin. In Table 3-1, a critical evaluation is performed to analyse to which extent other midpoint indicators are covered by these LCIs. From this evaluation it can be concluded that the LCIs sufficiently cover the impact categories. Most of the energy and transport processes were drawn from the Ecoinvent database and therefore most of the environmental flows were

[4] Available online at: http://blonkconsultants.nl/en/publications/2013/carbon-footprint-animal-feed.html

captured. These processes are listed in the inventory tables by their Ecoinvent names in the following sections.

Table 3-1: Critical evaluation of the LCIs developed for the Dutch Product Board Animal Feed (PDV)

Impact category	Critical evaluation
Climate change	The LCIs were developed for this impact category
Terrestrial acidification	The impact was calculated based on the amount of nitrogen applied and is therefore covered by the LCI
Freshwater eutrophication	The impact was calculated based on the amount of phosphorus applied and is therefore covered by the LCI
Marine eutrophication	The impact was calculated based on the amount of nitrogen applied and is therefore covered by the LCI
Agricultural land occupation	The impact was calculated based on the yield, mass balances and allocation and is therefore covered by the LCI
Natural land transformation	The impact was calculated based on yield, mass balances and allocation together with a method to calculate land use change.
Fossil depletion	The impact was calculated based on the amount of energy and type of fuel used and is therefore covered by the LCI

Table 3-2 gives an overview of the main parameters for the cultivation of the crops for the main raw materials of dairy compound feed. The full LCI's for the cultivation and processing of all feed ingredients as well as the market mixes are published in the reports mentioned above and are available online[5].

Table 3-2: Overview of the main parameters of the main feed raw materials (full LCI's available online)

	Origin	Yield	Fertilizer	Fertilizer	Fertilizer	Lime	Manure	Diesel
	%	kg/ha	kg N/ha	kg P2O5/ha	kg K2O/ha	kg/ha	kg N/ha	MJ/ha
maize[6] - Germany	50%/ 33%	8788	135	45	75	400	62	14390
maize[6] - France	50%/ 33%	8559	160	55	47	400	29	12304
maize - USA	33%	9139	64	62	43	23	14	11195
oil palm - Indonesia	28%	18200	95	69	181	400	19	4778
oil palm - Malaysia	72%	21300	130	77	270	400	27	4526
rapeseed - France	50%	3135	200	46	82	393	29	3723
rapeseed - Germany	50%	3610	200	46	82	393	62	4152
soybeans - Argentina	43%	2480	1	60	0	400	12	4092
soybeans - Brazil	54%	2442	3	86	30	400	41	3755
soybeans - USA	3%	2700	11	67	60	335	14	3207
sugar beet - Germany	10%	58938	150	60	160	417	62	7367
sugar beet - Netherlands	90%	63650	150	79	60	417	170	7161
wheat - France	27%	6565	161	21	22	13	29	5576
wheat - Netherlands	9%	8218	145	3	9	400	170	6112
wheat - United Kingdom	23%	7492	192	20	41	400	39	6283
wheat - Germany	42%	7129	150	21	20	400	62	6204

[5] http://blonkconsultants.nl/publicaties/2013/carbon-footprint-diervoeder.html

[6] 50% when incorporated in the feed as maize, and 33% when incorporated in the feed as co-products from wet or dry milling of maize.

3.1.1.2 Roughage

Three types of roughage are produced on the dairy farm: fresh grass, grass silage and corn silage. Primary data sources for the cultivation of fresh grass, grass silage and corn silage were Centraal Bureau voor de Statistiek for the yield (CBS, 2011), Binternet (Wageningen UR, 2012a) for fertilizer use and Handboek Melkveehouderij for cultivation operations, properties of materials like dry matter content and material use (Wageningen UR, 2012b). Emissions to air, water and soil have been calculated based on IPCC guidelines (IPCC, 2006c), see section 2.3. These data were used to model the cultivation of fresh grass, grass silage and corn silage, and summarised in Table 3-3, Table 3-4 and Table 3-5.

The cultivation operations (diesel consumption) are underestimated, as only the operations directly required for yield of the crop are included. The soil cultivation operations like tillage have not been included for the cultivation of grass and corn, but since grass cultivation requires soil operations only once every few years the underestimation is not very large for grass. Tillage has been included for the cultivation of feed raw materials for concentrates, protein rich feeds and wet by-products. Fresh grass is eaten in the field by the animals, but is also mowed for making grass silage. This is shown by the fact that fresh grass is an input for grass silage. Fresh grass and the corn are both fertilised by application of the dairy manure produced on the farm (see Chapter 3.1.2). The average dairy farm generally produces too much manure. According to Binternet 1540 kg N in 2011 is removed from the farm and applied by someone else, whereas the dairy farm also buys 850 kg N from manure in 2011. Dairy manure generally has a nitrogen content of 4.1 kg N/ton and a phosphorous content of 1.5 kg P_2O_5/ton (www.kennisakker.nl). This means that 690 kg N and 252 kg P_2O_5 are removed from the dairy farm to be applied to the soil by someone else. For nitrogen and phosphorous in manure that is removed from the farm to be applied to the soil by someone else, the cut-off rule is used (see Chapter 2.2.8). This means that the emissions due to application of manure that is removed from the farm are allocated to the next crop system for 100%. According to Binternet synthetic fertiliser is also applied on the dairy farm. The assumption has been made that all synthetic fertiliser is applied to the grass and not to the corn.

Manure is produced on the farm (See chapter 3.1.2) and part of the manure is removed from the farm, as mentioned above. The manure is not dedicated to either corn or grass, but modelled as one process for manure application with emissions calculated according to the IPCC, so they are not in the inventory tables for maize and grass cultivation.

Table 3-3: Inventory for cultivation of fresh grass.

Products	Quantity	Unit	Comment
Grass, fresh, at farm	68,074	kg	As is, 16% dry matter
Resources			
Occupation, arable	1	ha a	
Materials/fuels			
Fertilising, by broadcaster/CH U	1	ha	
Ammonium nitrate, as N, at regional storehouse/RER U	146	kg	
Triple superphosphate, as P_2O_5, at regional storehouse/RER U	3	kg	
Emissions to air			
Ammonia	17.7	kg	ammonia emissions due to fertilizer application
Dinitrogen monoxide	2.29	kg	direct emissions due to fertilizer application
Dinitrogen monoxide	0.229	kg	indirect emissions due to emission of ammonia
Dinitrogen monoxide	0.516	kg	indirect emissions due to leaching of nitrate
Emissions to water			
Nitrate	194	kg	
Emissions to soil			
Fertiliser, applied (P component)	1.31	kg	

Fresh grass produced at the farm is used as an input for the LCI of grass silage.

Table 3-4: Inventory for production of grass silage.

Products	Quantity	Unit	Comment
Grass silage, at farm	23,200	kg	As is, 47% dry matter
Resources			
Occupation, arable	1	ha a	
Materials/fuels			
Grass, fresh, at farm	68,100	kg	
Mowing, by rotary mower/CH U	1	ha	
Fodder loading, by self-loading trailer/CH U	109	m3	~ 213 kg/m3
Polyethylene, HDPE, granulate, at plant/RER U	90.4	kg	7.8 kg HDPE per ton dry matter for covering the heaped pile

Table 3-5: Inventory for production of corn silage.

Products	Quantity	Unit	Comment
Corn silage, at farm	46,500	kg	As is, 30% dry matter
Resources			
Occupation, arable	1	ha a	
Materials/fuels			
Fertilising, by broadcaster/CH U	1	ha	For fertilising with dairy manure
Ammonium nitrate, as N, at regional storehouse/RER U	0	kg	
Triple superphosphate, as P_2O_5, at regional storehouse/RER U	0	kg	
Chopping, maize/CH U	1	ha	
Fodder loading, by self-loading trailer/CH U	194	m3	240 kg/m3

Polyethylene, HDPE, granulate, at plant/RER U	146	kg	10.45 kg HDPE per ton dry matter for covering the heaped pile
Emissions to air			
Ammonia	0	kg	ammonia emissions due to fertilizer
Dinitrogen monoxide	0	kg	direct emissions due to fertilizer
Dinitrogen monoxide	0	kg	indirect emissions due to volatilisation
Dinitrogen monoxide	0	kg	indirect emissions due to leaching
Emissions to water			
Nitrate	0	kg	nitrate emissions due to fertilizer
Emissions to soil			
Fertiliser, applied (P component)	0	kg	emissions to soil due to P_2O_5 fertilizer corrected for molar mass

3.1.2 Production of raw milk

For this study the most recent data for the average Dutch dairy farm have been used. Primary data sources are:

- Binternet: for on-farm energy consumption, herd size, slaughtered cows, sold calves, fertilizer application for roughage production and prices of raw milk, meat and calves.
- CBS Statline: herd size, ratio of other animal types to dairy cows.
- CBS (CBS, 2011, CBS, 2008): for milk yield, feed intake, nitrogen and phosphorous excretions of the animals, liquid manure production and time spent outside in the pasture.
- Dutch NIR (CBS et al., 2011): for emissions of methane due to enteric fermentation.
- IPCC guidelines (IPCC, 2006a): for emissions from livestock and manure management.

The herd at the average Dutch dairy farm consists of about 82 dairy cows (Table 3-6). Hardly any male animals are kept, while most female calves are kept and raised for herd replacement. Most of the male calves and part of the female calves which are not needed for herd replacement are sold shortly after birth. This means that on average 45 calves are sold each year. The dairy cows which are slaughtered equals a live weight of 14,400 kg each year. The average milk yield per dairy cow in 2011 in the Netherlands is 8,063 kg per year, so the milk yield for the average Dutch dairy farm is 661,972 kg per year.

Table 3-6: Herd size at the average Dutch dairy farm.

animal type	# animals
female calves < 1 yr	30.0
male calves < 1 yr	1.8
female calves 1-2 yr	28.9
male calves 1-2 yr	0.6
dairy cows	82.1
bulls	0.4
heifers	4.4

Energy consumption at a dairy farm includes electricity, diesel and natural gas. The diesel consumption is fully assigned to the cultivation and production of roughage mentioned in 3.1.1.2. The consumption of electricity and natural gas is mentioned in Table 3-7.

Table 3-7: Energy consumption at the average Dutch dairy farm.

energy source		
electricity	kWh/farm/year	38,300
natural gas	MJ/farm/year	37,980

The feed ration on the average Dutch dairy farm (CBS, 2010) is displayed in Table 3-8. The dairy cows have a ration of concentrates which consist of a base concentrate and protein rich additives, fresh grass which they eat in the pasture, grass silage, corn silage and wet by-products like for instance brewers spent grain. The calves spend relatively more time in the pasture where they eat mainly grass. During the time the calves are very young and stabled they are fed raw milk directly from the cows. The amount of milk fed to calves is 200 kg per calf, fed during an 8 week period (CBS, 2010). This milk is accounted for because it is produced by the cows, but does not end up in the milk tank. The rest of the ration consists of concentrates, grass silage and corn silage. The heifers were assumed to be fed the same ration as the female calves 1-2 years of age. On average the bulls are kept in the stable where they are fed concentrates and grass silage.

Table 3-8: Feed ration of the animals on the average Dutch dairy farm in kg dry matter (dm) per animal per year.

	concentrates and protein-rich products	fresh grass	grass silage	corn silage	wet by-products
	kg dm/ animal/year	kg dm/ animal/year	kg dm/ animal/year	kg dm/ animal/year	kg dm/ animal/year
female calves < 1 yr	313.5	246.5	890	114	0
male calves < 1 yr	275	420	575	575	0
female calves 1-2 yr	83.5	1,182.5	1,666.5	77	0
male calves 1-2 yr	297	0	2956	0	0
dairy cows	1,772	997	2,245.5	1,736	321
bulls	297	0	2,956	0	0
heifers	83.5	1,182.5	1,666.5	77	0
dry matter content (%)	100%	16%	47%	30%	38%

The contents of the compound feed and protein-rich products as well as the wet by-products have been based on the analysis of the yearly throughput of feed raw materials, specifically for dairy, of an animal feed manufacturer (Anonymous, 2013). The energy consumption for the manufacturing of the compound feed is based on the study which was performed for the Dutch Product Board Animal Feed (PDV) by Wageningen University and Blonk Consultants in which life cycle inventories (LCIs) were developed for the cultivation of crops used in compound feeds. The ingredients are cultivated all over the world and the Dutch mix consists of multiple cultivation countries for most ingredients. This is explained in the references mentioned in 3.1.1.1. The wet by-products are fed as separate feeds and do not need to be pelletized. Transport of feed ingredients (raw materials) to the factory is included in the raw materials. It is assumed that the feed is transported from the production site to the farm over 50 km by truck and 50 km by barge ship (see Table 3-9 and Table 3-10).

Table 3-9: LCI for the manufacturing of compound feed for dairy (base feed and protein-rich).

Products	Quantity	Unit	Comment
Dairy compound feed (basic + protein) NL	93	kg	As fed. The average dairy feed contains many ingredients in very small amounts. A dairy feed has been made with the top ingredients. The extra impact is estimated by not making a reference flow of 100 kg (because not 100% of the ingredients are accounted for) but for 93 kg.
Materials/fuels			
Barley NL	1	kg	Dutch market average
Citrus pulp dried NL	8.5	kg	Dutch market average
Maize gluten meal NL	1	kg	Dutch market average
Maize NL	18	kg	Dutch market average
Palm kernel meal, solvent extracted NL	13.5	kg	Dutch market average
Rapeseed meal Mervobest NL	17	kg	Dutch market average
Soybean hulls CF 320-360 NL	1.5	kg	Dutch market average
Soybean meal CF 45-70 CP 0-450 NL	11	kg	Dutch market average
Sugarbeet molasses NL	4	kg	Dutch market average
Sugarbeet pulp SUG 150-200 NL	4.5	kg	Dutch market average
Triticale NL	2.5	kg	Dutch market average
Wheat gluten feed NL	3.5	kg	Dutch market average
Wheat middlings NL	1	kg	Dutch market average
Wheat NL	6	kg	Dutch market average
Transport, lorry 20-28t, fleet average/CH U	4.65	tkm	
Transport, barge tanker/RER U	4.65	tkm	
Inputs from techno sphere			
Natural gas, burned in industrial furnace >100kW/RER U	12.6	MJ	
Electricity, production mix NL/NL U	29.3	MJ	

Table 3-10: LCI for the mix of wet by-products fed to dairy cows.

Products	Quantity	Unit	Comment
Dairy wet by-product feed NL	100	kg	As fed
Materials/fuels			
Brewers' grains (22% dm) NL	18	kg	22% dry matter, Handboek Melkveehouderij 2012, chapt 6, table 6.24
Potato pulp pressed fresh+silage NL	14	kg	16% dry matter
Sugarbeet pulp SUG 150-200 NL	23	kg	22% dry matter
Soybean meal CF 45-70 CP 0-450 NL	18	kg	16% dry matter
Rapeseed meal Mervobest NL	9	kg	88% dry matter
Wheat NL	9	kg	87% dry matter
Maize NL	9	kg	87% dry matter
Transport, lorry 20-28t, fleet average/CH U	5	tkm	
Transport, barge tanker/RER U	5	tkm	

The animals on the dairy farm excrete nitrogen, and phosphorous through manure and emit methane through enteric fermentation (Table 3-11). These excretions and emissions have an impact on climate change, marine and freshwater eutrophication and terrestrial acidification.

Table 3-11: Yearly excretion of nitrogen, phosphorous and manure, and emission of methane due to enteric fermentation for each animal type on the average Dutch dairy farm.

	N-excretion	P_2O_5-excretion	manure production	enteric fermentation
	kg N /animal/year	kg P_2O_5 /animal/year	kg /animal/year	kg CH_4 /animal/year
female calves < 1 yr	34.8	9.4	5,000	29.1
male calves < 1 yr	32.4	8.2	5,000	33.5
female calves 1-2 yr	71.2	21.5	12,500	57
male calves 1-2 yr	82.7	25.5	12,500	59.4
dairy cows	127.6	40.6	26,000	128.7
bulls	82.7	25.5	12,500	59.4
heifers	71.3	21.5	12,500	57
Per kg of raw milk	**0.021**	**0.007**	**10.534**	**0.020**

The animals on an average Dutch dairy farm spend part of their time outside in the pasture. The time spent on the pasture has an effect on the ration of excretions dropped in the stable and on the pasture. This affects the impact on climate change, marine and freshwater eutrophication and terrestrial acidification. Emissions from excretion in the stable are different from emissions from excretion in the pasture. In the stable the manure needs to be stored for instance, which leads to extra emissions. The emissions from manure storage, manure application and manure excreted in the pasture are explained in 2.3. Days spent on the pasture reflect full 24 hours spent outside. The calves up to 1 year of age spend 37 days outside (10% of the year). The calves between 1 and 2 years of age spend 88 days outside (24% of the year). Dairy cows spend 35 days outside (9.6% of the year).

The dairy farm produces three types of products which are sold: raw milk, animals for slaughter and calves. In the IDF method a physical allocation method is used. This method reflects the underlying use of feed energy by the dairy cows and the physiological feed requirements of the animal to produce milk and meat (IDF, 2010). This method leads to the following allocation fractions:

- Raw milk: 85.95%
- Live weight animals: 12.35%
- Calves: 1.70%

Another factor that affects the environmental impact of raw milk is the amount of peat land which is used on the dairy farm. The share of peat land on an average Dutch dairy farm was assumed equal to the amount of peat land used for agricultural purposes in the Netherlands relative to the total amount of land used for agricultural purposes. The NIR reports that the amount of peat land used for agricultural purposes is 223,000 hectares (NIR, 2012). CBS Statline (CBS, 2013) reports that the total amount of land used for agricultural purposes is approximately 1,842,000 hectares. When assumed that the share of peat land on an average Dutch dairy farm was equal to the amount of peat land used for agricultural purposes in the Netherlands the estimate for the percentage of land for dairy farming that is peat land is 12.1%.

The raw milk is transported from the dairy farm to the production locations of semi-skimmed milk or semi-mature cheese. We do not have specific primary data regarding the collection process of the milk, so the transport of milk from the farm to the factory is based on assumptions. Based on the average milk yield per cow per day and the average amount of dairy cows per farm and the fact that the raw milk is collected approximately once every two days and one truck collects the raw milk from approximately six dairy farm during one round (website FrieslandCampina), the truck needs to have at least a load capacity of 26 tons. It is assumed that the truck needs to drive approximately 100 kilometres to collect the milk at six farms and deliver it to the production location. The collection of milk has been incorporated in the LCI's of the production of semi-skimmed milk and semi-mature cheese in Chapters 3.1.3 and 3.2.

3.1.3 Production of semi-skimmed milk

At FrieslandCampina, semi-skimmed milk is produced at two production locations. Primary data (Table 3-12 – anonymised) have been obtained from both production locations regarding water use, energy consumption, use of refrigerants and waste water treatment. The mass balance for the production of semi-skimmed milk from raw milk and the contents of the products produced were obtained via experts from FrieslandCampina (Willem Vogel). Prices were also obtained via experts from FrieslandCampina (Lieuwe Montsma). In this study we assumed that 50% of the semi-skimmed milk was produced in both production locations.

Table 3-12: Process for the production of semi-skimmed milk

Products
Semi-skimmed milk production 2011
Cream production 2011 (from milk)
Residue production 2011
Inputs from nature
Water, groundwater consumption
Materials/fuels
Milk
Tap water, at user/RER U
Chlorodifluoromethane, at plant/NL U
Refrigerant R134a, at plant/RER U
Transport, lorry 16-32t, EURO4/RER U
Emissions to air
Natural gas, burned in industrial furnace >100kW/RER U
Electricity, production mix NL/NL U
Outputs to techno sphere
Treatment, sewage, to wastewater treatment, class 3/CH U

Primary data related to packaging of semi-skimmed milk have been obtained via FrieslandCampina (Taco Kingma/ Klaas Kuiper). The package for 1 litre of milk (gable top) weighs 29.85 grams (Table 3-13). The packaging consists of carton and an LDPE lining. The cap consists partly of LDPE and partly of HDPE. The basis for the production of the packaging for semi-skimmed milk is an Ecoinvent process (Production of liquid packaging board containers, at plant/RER), which has been adapted to the materials used for the packaging of FrieslandCampina.

Table 3-13: Materials used for the production of the packaging of semi-skimmed milk.

material	Ecoinvent process
carton	Liquid packaging board, at plant/RER U
LDPE lining	Polyethylene, LDPE, granulate, at plant/RER U
LDPE - cap	Polyethylene, LDPE, granulate, at plant/RER U
HDPE - cap	Polyethylene, HDPE, granulate, at plant/RER U
Total	Milk package (gable top)

3.2 1 kg semi-mature cheese (jongbelegen 48+)

For the production of semi-mature Gouda cheese the production stages up to raw milk delivery at the factory gate are equal to the production of semi-skimmed milk. The LCI for these phases is presented in 3.1.1 and 3.1.2. Subsequently the delivered raw milk is used for the production of semi-mature Gouda cheese.

There is one production location for this cheese at FrieslandCampina (Table 3-14). The type of cheese analysed for this study is a wheel which is naturally ripened/mature, so not in a foil. Before maturation the cheese is coated with polyvinyl acetate (0.32 gram per kg of raw milk, Anton Sweere). After production the cheese is stored for maturation during 4-6 weeks (Anton Sweere). During this period the cheese loses about 2.9% of its weight in water. The data for the curing of the cheese are from warehouses in two locations, but often the cheese is stored on the production site (Eef van Arem, FrieslandCampina). After curing the cheese is cut (0.7% cutting losses) and packed. Primary data on water use, energy consumption, use of refrigerants and waste water treatment have been obtained from the production location as well as the storage locations. The mass balance for the production of semi-mature Gouda cheese from raw milk was obtained via experts from FrieslandCampina (Anton Sweere). For this analysis we assumed that 50% of the semi-mature Gouda cheese is stored in both locations.

Table 3-14: Process for the production of semi-mature Gouda cheese

Products
Gouda 48+ production
Cream production (from cheese)
Whey production
Inputs from nature
Water, groundwater consumption
Materials/fuels
Milk
Tap water, at user/RER U
Chlorodifluoromethane, at plant/NL U
Refrigerant R134a, at plant/RER U
Transport, lorry 16-32t, EURO4/RER U
Inputs from techno sphere
Natural gas, burned in industrial furnace >100kW/RER U
Electricity, production mix NL/NL U
Outputs to techno sphere
Treatment, sewage, to wastewater treatment, class 3/CH U

Table 3-15: Process for the storage/ curing of semi-mature Gouda cheese

Products
Gouda 48+ storage
Inputs from nature
Water, groundwater consumption
Materials/fuels
Gouda 48+ production
Tap water, at user/RER U
Chlorodifluoromethane, at plant/NL U
Refrigerant R134a, at plant/RER U

Inputs from techno sphere
Natural gas, burned in industrial furnace >100kW/RER U
Electricity, production mix NL/NL U
Outputs to techno sphere
Treatment, sewage, to wastewater treatment, class 3/CH U

The semi-mature Gouda cheese is cut in wedges and packed in a plastic foil. The foil is built up of multiple layers of different types of material. Finally the packed wedge is labelled. The layers of the foil are made from nylon, low density polyethylene (LDPE) and ethylene-vinyl alcohol (EVOH). The label is made from paper. All data were obtained from FrieslandCampina (Ronald Schraa). The amount of coating of the cheese was obtained from Anton Sweere (0.32 g/kg raw milk). The data in Table 3-16 are corrected for cutting losses (Anton Sweere: 0.7%) and are per kg of cut and packed semi-mature Gouda cheese.

Table 3-16: Materials used for the production of the packaging of cut and packed semi-mature Gouda cheese.

material	Ecoinvent process
nylon	Nylon 6, at plant/RER U
LDPE	Packaging film, LDPE, at plant/RER U
EVOH	Ethylene vinyl acetate copolymer, at plant/RER U
paper	Kraft paper, bleached, at plant/RER U
cheese coating	Polyvinyl acetate

3.3 Retail, Consumer phase and Waste treatment

When the products have been manufactured they are distributed via distribution centres and supermarkets. This is the retail phase of the life cycle. In this phase electricity consumption is required for lighting and cooling in the distribution centre and the supermarket branch. Also natural gas is required for a comfortable climate for the consumers in the shop. The data used in this analysis for the retail phase are displayed in Table 3-17. The energy consumption for cooling in the supermarket has been tailor made for semi-skimmed milk and semi-mature Gouda cheese. We obtained data on the energy consumption per meter from the largest Dutch supermarket chain (Albert Heijn, 2013). This was combined with sales data (Productschap Zuivel, 2012; SymphonyIRI, 2010) to calculate the throughput. The throughput of semi-skimmed milk is much higher than of other products, which means that per kilogram of product less energy consumption is required for cooling. Cheese has a much slower throughput.

The distances from the manufacturer to the distribution centre and between the distribution centre and the supermarket branch are both assumed to be 50 kilometres.

Table 3-17: Energy consumption in the retail phase for the products in systems 1a, 1b, 2a, 2b and 2c.

Product	**lighting distribution centre**	**cooling distribution centre**	**lighting supermarket**	**cooling supermarket**	**heating supermarket**
	kWh/kg	**kWh/kg**	**kWh/kg**	**kWh/kg**	**kWh/kg**
semi-skimmed milk	0.04	0.07	0.036	0.05	0.079
semi-mature Gouda cheese	0.04	0.07	0.036	0.42	0.079

In the consumer phase energy is required for cooling. The data used in this analysis for the consumer phase were derived from several sources (Carlsson-Kanyama & Boström-Carlsson, 2001; Dutilh, Velthuizen, & Blonk, 1996; Van Elburg, 2008). Furthermore, we did some tentative measurements on energy use of cooling appliances to check if the data were a good estimate for the Netherlands.

Table 3-18: Energy consumption in the consumer phase for the products in systems 1a, 1b, 2a, 2b and 2c.

Product	**cooling consumer**	**cooking consumer - natural gas**	**cooking consumer - electricity**
	kWh/kg	**MJ/kg**	**kWh/kg**
semi-skimmed milk	0.047	-	-
semi-mature Gouda cheese	0.047	-	-

Besides the energy consumption in the consumer phase, there is also a difference between the amount of product purchased and the amount of product consumed. Conversion factors necessary to calculate the right mass balance for the consumer phase are adopted from two sources (Table 3-19). A recent study by CREM collected data on avoidable food waste in the consumer phase by analysis of garbage from households (Van Westerhoven & Steenhuizen, 2010). The conversion factor for the edible part and the raw to cooked ratio originated from the most recent dietary survey (Rossum, Fransen, Verkaik-Kloosterman, Buurma-Rethans, & Ocké, 2011).

Table 3-19: Conversion factors needed for the mass balance of consumer phase. The edible part, the avoidable waste part and the fraction raw to cooked for the products in systems 1a, 1b, 2a, 2b and 2c.

Product	kg edible per kg raw	kg avoidable waste per kg raw	kg cooked per kg raw
semi-skimmed milk	1.00	0.054	1.0
semi-mature Gouda cheese	0.99	0.028	1.0

The organic waste from the consumer phase as well as packaging material were treated in an end of life scenario. The waste treatment chosen for this analysis is incineration with energy recovery, which is common practice in the Netherlands. Data regarding the amount of energy recovery vary, but we have chosen for 20% energy recovery in the form of electricity and 5% energy recovery in the form of heat (natural gas replacement) (BRBS, 2008). The recovery of energy replaces the production of primary energy and is accounted for as an avoided emission.

The incineration processes in the Ecoinvent database were used as a basis for the environmental impact of incineration of bio-waste and packaging materials. These processes have been altered to include the recovery of electricity and heat based on the energy content of the materials being incinerated (see Table 3-20).

Table 3-20: Base processes from the Ecoinvent database and the energy content of the materials being incinerated with energy recovery.

Material	Base process in Ecoinvent	Energy content (MJ/kg)
bio-waste	Disposal, biowaste, 60% H2O, to municipal incineration, allocation price/CH U	5.1
cardboard	Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	15.92
paper	Disposal, packaging paper, 13.7% water, to municipal incineration/CH U	14.12
plastic mix	Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH U	30.79
PE	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	42.47

4 Life Cycle Impact Assessment Results

This chapter contains the results on the environmental impact of semi-skimmed milk and semi-cured Gouda cheese. The results will be discussed in the interpretation and discussion section (chapter 0).

4.1 Semi-skimmed pastuerized milk

Table 4-1 shows the characterised impact assessment results for semi-skimmed milk.

Table 4-1: Characterised impact assessment results for 1 kg semi-skimmed milk.

Impact category	Unit	1 kg Semi-skimmed milk
Climate change	kg CO_2 eq	1.12
Terrestrial acidification	kg SO_2 eq	0.021
Freshwater eutrophication	kg P eq	0.00035
Marine eutrophication	kg N eq	0.0071
Agricultural land occupation	m^2a	0.91
Fossil depletion	kg oil eq	0.14

4.2 Semi-cured Gouda cheese

Table 4-2 shows the characterised impact assessment results for semi-cured Gouda cheese.

Table 4-2: Characterised impact assessment results for 1 kg semi-cured Gouda cheese.

Impact category	Unit	1 kg Semi-cured Gouda cheese
Climate change	kg CO_2 eq	8.67
Terrestrial acidification	kg SO_2 eq	0.188
Freshwater eutrophication	kg P eq	0.00294
Marine eutrophication	kg N eq	0.0637
Agricultural land occupation	m^2a	6.27
Fossil depletion	kg oil eq	0.84

5 Interpretation

The interpretation includes the environmental impact of semi-skimmed milk and semi-cured Gouda cheese including a contribution analysis of the different life cycle stages, a sensitivity analysis, an uncertainty analysis as well as the limitations of the methods. The interpretation is meant to gain more insight in the major contributing phases and how sensitive the results were to the assumptions in the model. These insights are summarised and reflected upon in the the discussion section (chapter 6).

5.1 Semi-skimmed pasteurized milk

Table 5-1 shows the quantification of the contribution from different life cycle stages to the environmental impact of semi-skimmed milk. The contribution analysis is visualized in Figure 5-1..

Table 5-1: Quantification of the contribution from different life cycle stages to the impacts on climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation and fossil depletion for 1 kg semi-skimmed milk.

Impact category	**Unit**	**dairy farm**	**production of semi-skimmed milk**	**retail**	**packaging**	**consumer**	**waste treatment**
Climate change	kg CO2 eq	0,84	0,05	0,18	0,03	0,03	-0,02
Terrestrial acidification	kg SO2 eq	0,021	9,21E-05	3,26E-04	1,29E-04	4,39E-05	-2,22E-05
Freshwater eutrophication	kg P eq	0,00030	1,11E-05	3,71E-05	6,32E-06	7,97E-06	-6,19E-06
Marine eutrophication	kg N eq	0,0070	2,26E-05	2,36E-05	1,13E-05	3,62E-06	7,39E-07
Agricultural land occupation	m2a	0,70	3,70E-04	2,03E-03	2,16E-01	4,44E-04	-4,52E-04
Fossil depletion	kg oil eq	0,05	1,63E-02	6,00E-02	1,53E-02	1,03E-02	-1,12E-02

For most of the impact categories the dairy farm is the most contributing life cycle stage (75% - 99%). Fossil depletion is the only impact category to which all life cycle stages have a significant contribution, except for the life cycle stage of the production of semi-skimmed milk. The retail stage has a considerable contribution to climate change (~16%), freshwater eutrophication (~10%) as well as fossil depletion (~42%). This contribution is mostly caused by the energy use for cooling and lighting in the distribution centre and the supermarket. The packaging has a considerable contribution to agricultural land occupation (~24%). This is caused by the fact that the packaging is largely made from liquid packaging board which requires trees as a main source of material. The packaging as well as the organic waste resulting from the consumer stage were treated at the end of the life cycle. The impact of waste treatment is negative because the incineration involves recovery of electricity and heat (natural gas), which were treated as avoided emissions here (see chapter 3.3).

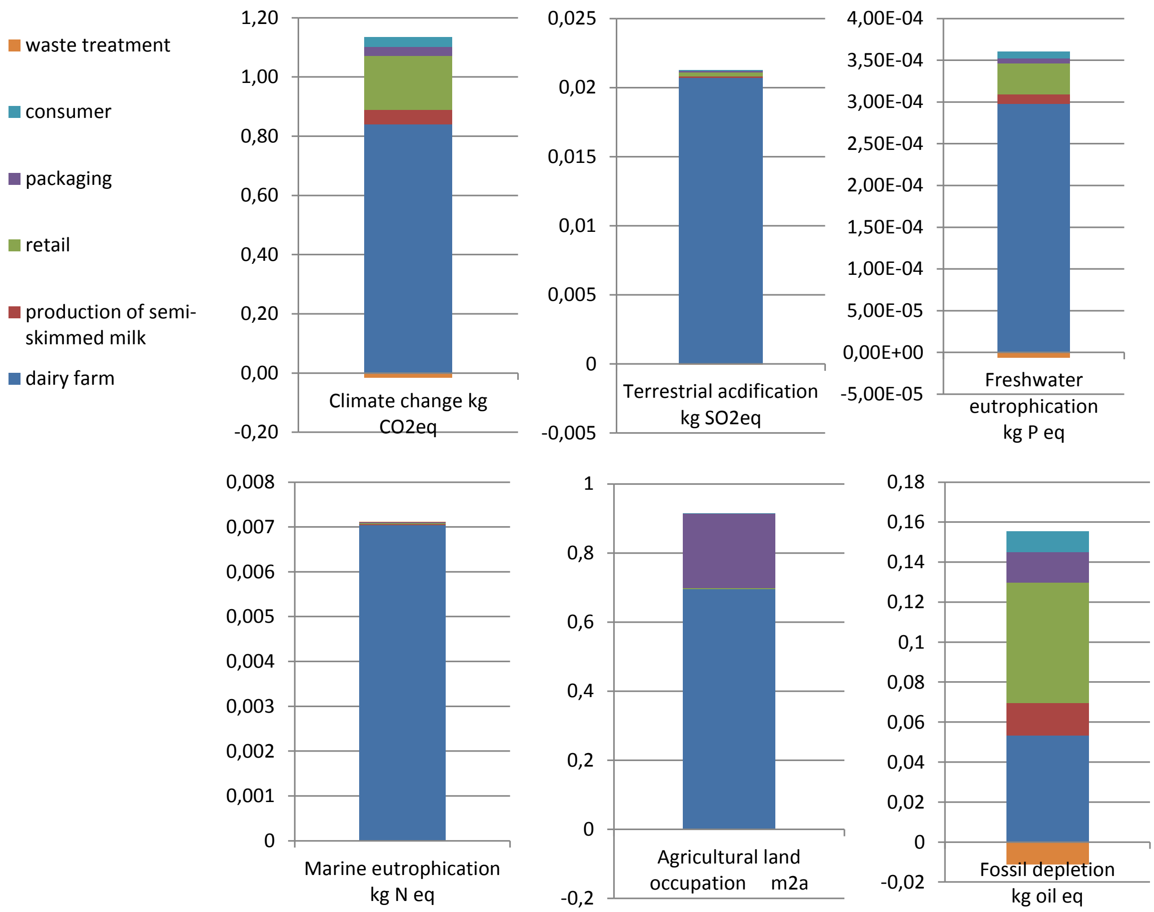

Figure 5-1: Contribution of different life cycle stages to the impact categories climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation and fossil depletion for one functional unit of 1 kg of semi-skimmed milk.

As mentioned the dairy farm has a considerable contribution to most of the impact categories, which is why the different contributions on the dairy farm are explained in more detail in Figure 5-2 for a reference of 1 kg of raw milk.

Enteric fermentation from cattle has a considerable contribution to the impact category climate change of raw milk (~ 35%). Manure, excreted either in the stable or on the pasture, manure application and storage are a second important source. Also the production of feed has a considerable contribution to climate change (see Figure 5-2). The main impacts on terrestrial acidification are emissions of ammonia from manure management and application of manure for the cultivation of feed raw materials. Freshwater eutrophication and marine eutrophication are largely caused by the addition of manure to the soil, the production and application of synthetic fertilizer for the cultivation of feed ingredients. The cultivation of feed ingredients and especially the processing of feed raw materials for compound feed and by-products contribute to fossil depletion because of the consumption of energy for field work, processing and transport. On the dairy farm itself, energy is used for the cultivation of roughage and also for heating, lighting and cooling of the milk (~ 16% of impact on fossil depletion), but this might be slightly underestimated because not all operations on the field are included (see 3.1.1.2).

The impact on agricultural land occupation is caused by the cultivation of feed raw materials either for roughage, compound feed, protein rich feed or by-products. All roughage is cultivated on the dairy farm in the Netherlands. Impact on agricultural land occupation of grass is caused by feeding on fresh grass in the pasture (~ 32%) as well as by feeding grass silage (~ 68%). The feed raw materials for compound feed and protein rich feed and by-products are cultivated all over the world. The location of the cultivation for these feed ingredients is displayed in Figure 5-3 in m²a for the reference flow of 1 kilogram of raw milk.

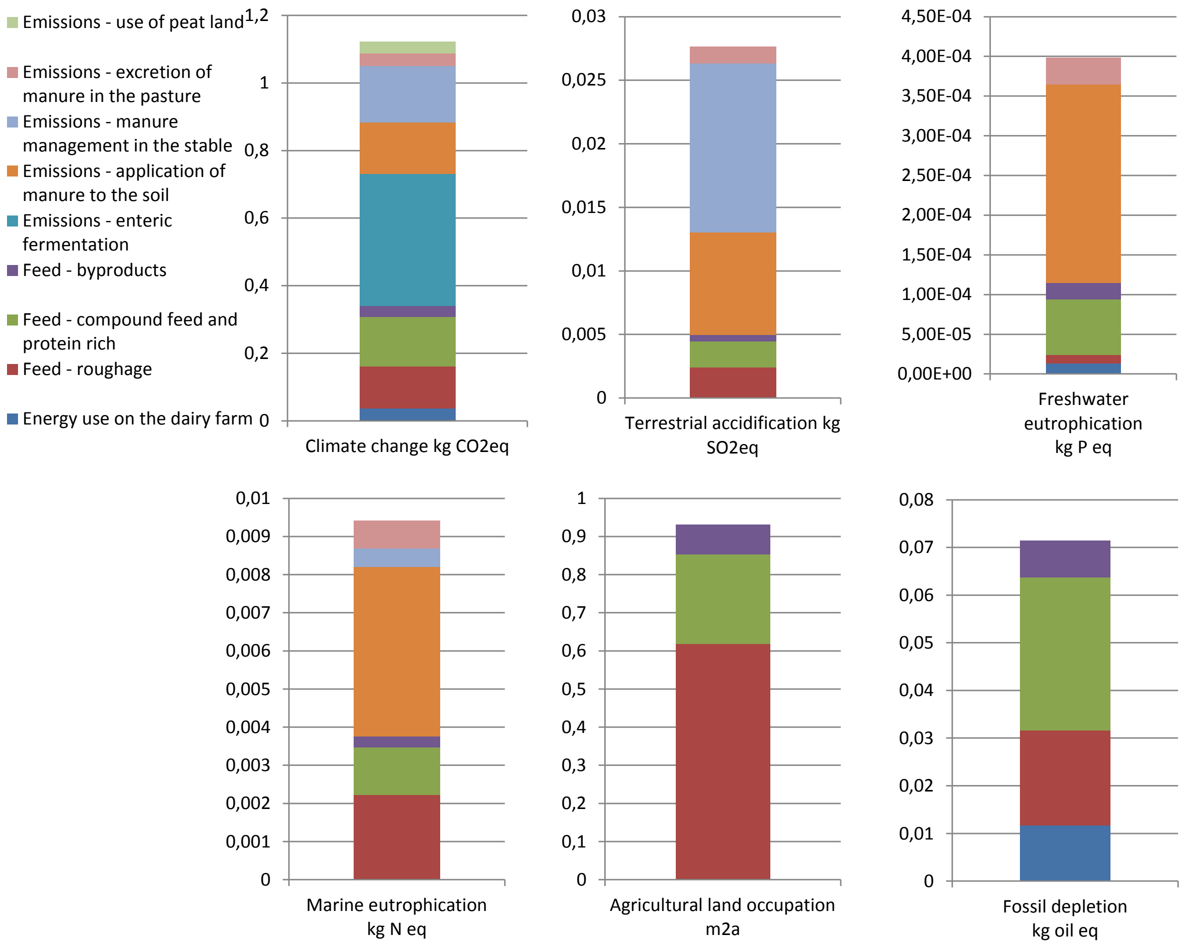

Figure 5-2: Contribution from different life cycle stages to the impacts on climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation and fossil depletion for 1 kg of raw milk.

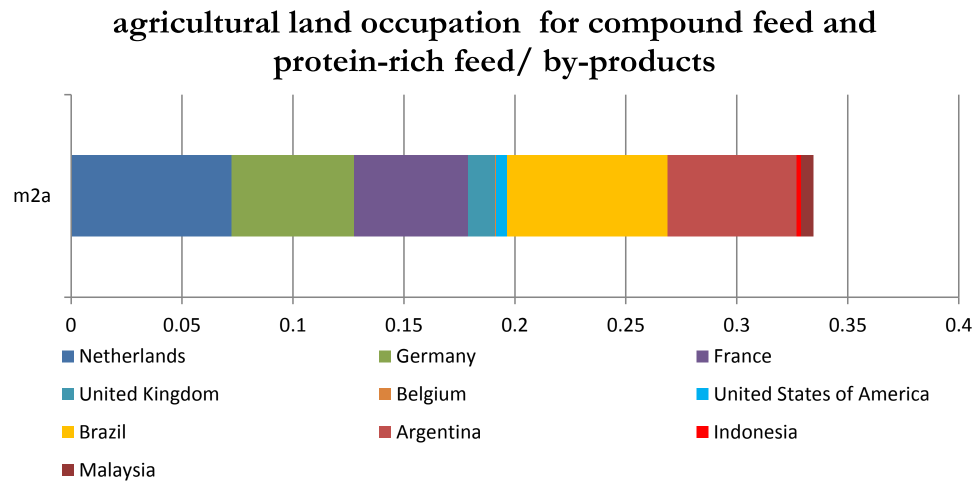

Figure 5-3: Location of agricultural land occupation for the cultivation of compound and protein rich feed and protein-rich feed/ by-products in m²a for 1 kg of raw milk.

5.2 Semi-cured Gouda cheese (jongbelegen 48+)

Table 5-2 shows the quantification of the contribution from different life cycle stages to the environmental impact of semi-mature Gouda cheese. The contribution analysis is visualized in Figure 5-4.

Table 5-2: Quantification of the contribution from different life cycle stages to the impacts on climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation and fossil depletion for 1 kg semi-cured Gouda cheese.

Impact category	Unit	dairy farm	production of semi-cured Gouda cheese	curing of the cheese	retail	packaging	consumer	waste treatment
Climate change	kg CO2 eq	7.56	0.51	0.08	0.44	4.54E-02	3.22E-02	4.99E-03
Terrestrial acidification	kg SO2 eq	0.19	9.17E-04	1.12E-04	6.74E-04	1.46E-04	4.39E-05	-1.50E-05
Freshwater eutrophication	kg P eq	2.68E-03	1.16E-04	3.10E-05	1.01E-04	6.72E-06	7.97E-06	-3.48E-06
Marine eutrophication	kg N eq	6.34E-02	2.58E-04	1.53E-05	5.23E-05	1.13E-05	3.62E-06	-2.00E-07
Agricultural land occupation	m2a	6.26	4.02E-03	1.08E-03	5.58E-03	7.96E-03	4.44E-04	-2.47E-04
Fossil depletion	kg oil eq	0.48	0.17	0.03	0.14	2.11E-02	1.03E-02	-6.14E-03

For most of the impact categories the dairy stage is the largest contributor. Climate change and fossil depletion are the only impact categories to which most of the life cycle stages have a considerable contribution. Processing of semi-mature Gouda cheese, maturation as well as the retail stage have a considerable contribution to climate change (~12%), freshwater eutrophication (~9%) as well as fossil depletion (~43%). This is caused by energy consumption for processing and the energy use for cooling and lighting in the distribution centre and the supermarket. Packaging hardly contributes to the environmental impact. The impact of waste treatment of the package and organic waste is negative for fossil depletion because incineration involves recovery of electricity and heat (avoided natural gas), which were treated as avoided emissions here (see chapter 3.3). Terrestrial acidification, freshwater eutrophication, marine eutrophication and agricultural land occupation are also associated with the production of electricity and natural gas. Since the production of electricity and natural gas is avoided the emissions are negative.

As mentioned the dairy farm has a relatively large contribution to most of the impact categories. In the chapter about semi-skimmed milk we have already explained the different contributions of the agricultural stage to the production of raw milk (Figure 5-2).

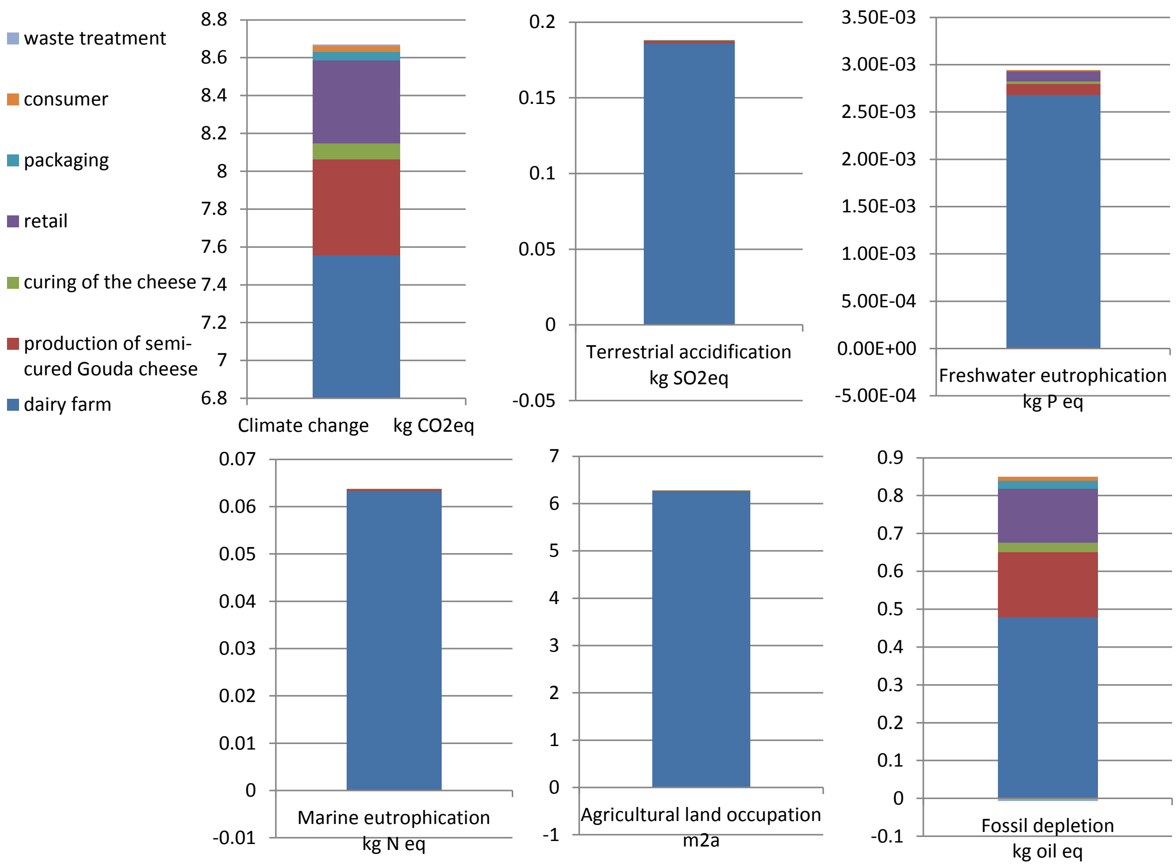

Figure 5-4: Contribution from different life cycle stages to the impacts on climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, agricultural land occupation and fossil depletion for 1 kg of Gouda cheese.

5.3 Identification of significant parameters

From the life cycle inventory and contribution analysis, it can be concluded that a number of parameters have a significant influence on the final outcomes of the study. The baseline comparison does not include impacts from land use change. To get an estimate of the effect of this exclusion a sensitivity analysis is performed that assesses the impact of land use change, using three different methods (see 5.4.1). As allocation affect the outcomes of the study, a sensitivity analysis is performed to estimate the effect of changing the allocation method for the farm outputs. We compare the IDF allocation to economic alloaction on the dairy farm (see 5.4.2).

5.4 Sensitivity analysis

Sensitivity analysis is a procedure to determine how changes in data and methodological choices affect the results of the LCIA. In this study, methodological choices investigated in the sensitivity analysis include the impact of land use change and the allocation method.

5.4.1 Impact due to LUC

For the base analysis the contribution of land use change (LUC) to climate change was not taken into account. In this sensitivity analysis the impact of land use change was analysed for semi-skimmed milk and semi-cured Gouda cheese. This is justified by the fact that it is not a main goal of the study to analyse and compare based on the impact of LUC, but the impact of LUC is explored in the sensitivity analysis.

There is no consensus on the best method to calculate climate change induced by LUC, which is why the impact of LUC is reported separately. Three methods have been selected to calculate the contribution of LUC to climate change in this sensitivity analysis:

- PAS2050-1 (BSI, 2012)
- UNEP-SETAC (Müller-Wenk & Brandão, 2010, Milà i Canals et al., 2012)
- Top down Approach (Vellinga et al., 2013)

The contribution of LUC to climate change for semi-skimmed milk and cemi-cured cheese, using three methods, are shown in Figure 5-5 and Figure 5-6. The geographical locations of the various crops are listed in Table 3-2.
The left bar in the figures is the result from the base analysis without LUC and the three bars to the right show the impact on climate change if LUC is included using the three methods mentioned above.

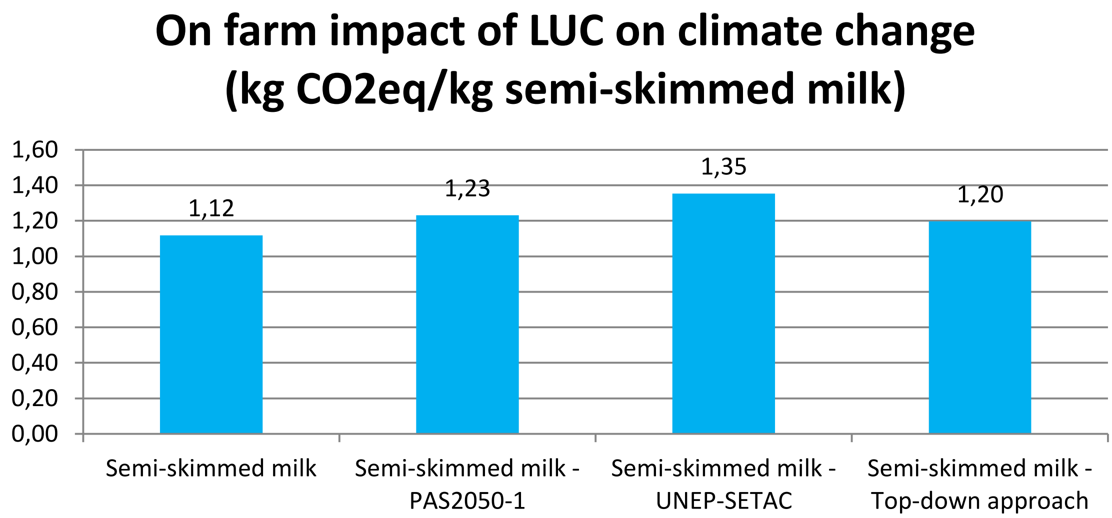

Figure 5-5: Impact of land use change on climate change for semi-skimmed milk, using three methods. The first bar (labelled semi skimmed milk) represents the baseline result, without any impacts from LUC.

Climate change of semi-skimmed milk increases by 10%, 21% and 7% using respectively PAS2050-1, UNEP-SETAC and the Top-down approach to calculate the contribution of LUC to climate change. The top-down approach does not distinguish between crops and applies an average value of 1.18 tonne CO_2eq/ha/year regardless of crop or country. For PAS2050-1 and UNEP-SETAC the main impact due to LUC is resulting from cultivation of the feed ingredient soybeans in Brazil (~52%, 12.4 tonne CO_2eq/ha/year resp. ~33%, 16.0 tonne CO_2eq/ha/year) and Argentina (~46%, 13.6 tonne CO_2eq/ha/year resp. ~65%, 39.7 tonne CO_2eq/ha/year). Another but minor contributor is cultivation of the feed ingredient oil palm fruit in Indonesia and Malaysia.

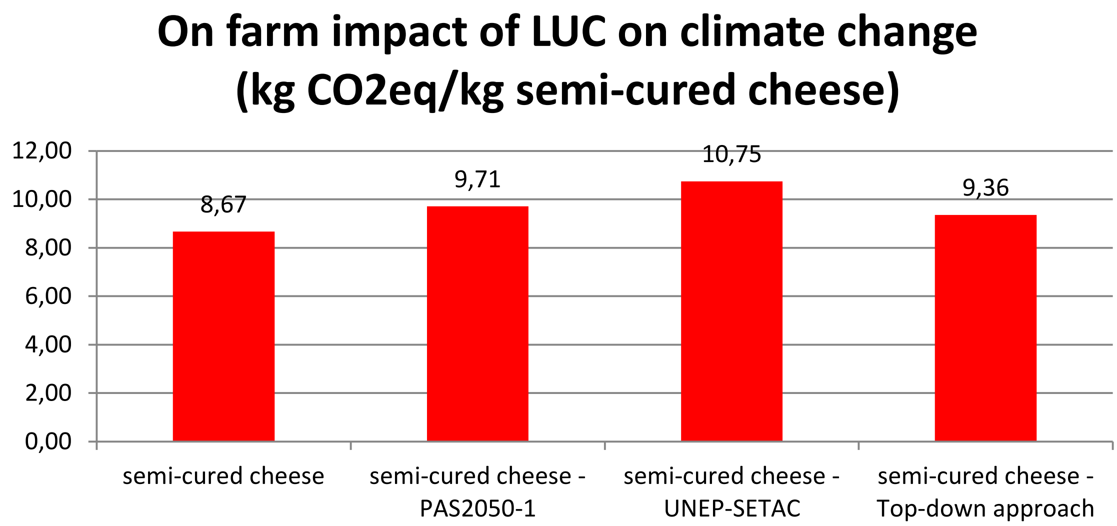

Figure 5-6: Impact of land use change on climate change for semi-mature Gouda cheese, using three methods. The first bar (labelled semi-mature Gouda cheese) represents the baseline result, without any impacts from LUC.

The impact of semi-cured Gouda chese increases by 12%, 24% and 8% using respectively PAS2050-1, UNEP-SETAC and the Top-down approach to calculate the impact of LUC on climate change. The top-down approach is too general to distinguish between crops and applies a value of 1.18 tonne CO_2eq/ha/year regardless of crop or country. For PAS2050-1 and UNEP-SETAC the main impact due to LUC is resulting from cultivation of the feed ingredient soybeans in Brazil (~52%, 12.4 tonne

CO_2eq/ha/year resp. ~33%, 16.0 tonne CO_2eq/ha/year) and Argentina (~46%, 13.6 tonne CO_2eq/ha/year resp. ~65%, 39.7 tonne CO_2eq/ha/year). Another but minor contributor is cultivation of the feed ingredient oil palm fruit in Indonesia and Malaysia.

5.4.2 Choice of allocation rules

With respect to allocation on the main products from the average dutch dairy farm, i.e. raw milk, animals for slaughter and calves a comparison is made between and the physical allocation according to the IDF method and economic allocation . In the IDF method a physical allocation method is used. This method reflects the underlying use of feed energy by the dairy cows and the physiological feed requirements of the animal to produce milk and meat (IDF, 2010). This method leads to the following allocation fractions:

- Raw milk: 85.95%
- Live weight animals: 12.35%
- Calves: 1.70%

The prices of raw milk, animals for slaughter and calves for economic allocation were based on 5 year averages from Binternet (2007-2011) (Wageningen UR, 2012a). The average price in this period was €0.339 per litre raw milk and €0.888 per kg live weight cow. The average price per calf is €140.00. Based on the revenue for milk, animals for slaughter and calves 92.2% of the environmental impact is allocated to raw milk, 5.2% to animals for slaughter, and 2.6% to calves.

This means that compared to IDF allocation more environmental impact is allocated to raw milk. As a result the environmental impact increases for 1 kg of semi-skimmed milk as shown in Table 5-3.

Table 5-3: Difference between economic allocation and IDF allocation for 1 kg of semi-skimmed milk.

Impact category	Unit	Semi-skimmed milk - IDF allocation	Semi-skimmed milk - economic allocation
Climate change	kg CO_2 eq	1.12	1.18
Terrestrial acidification	kg SO_2 eq	0.021	0.023
Freshwater eutrophication	kg P eq	0.00035	0.00038
Marine eutrophication	kg N eq	0.0071	0.0076
Agricultural land occupation	m^2a	0.91	0.96
Fossil depletion	kg oil eq	0.14	0.15

5.5 Uncertainty analysis

Uncertainty analysis is the procedure to determine how uncertainties in data and assumptions progress in the calculations and how they affect the reliability of the results of the LCIA. The uncertainty analysis was done as part of the impact assessment, to determine the variability of Life Cycle Inventory Data and emission factors on the LCA of the different products studied and to determine if differences found between equivalent systems were significant.

Monte Carlo analysis is used to determine statistical differences between the two Dutch dairy products and their equivalent systems with plant-based alternatives. A paired difference test with 5% significance level is used to determine if the differences were statistically significant. The Monte Carlo analysis is performed based on estimations of variability and distribution per data point and emission factor and the interrelation between data points (correlations which were taken into account were, for example, electricity which once sampled was repeated throughout the whole chain.).

5.5.1 *Uncertainty analysis set-up*

The uncertainty analysis was run in SimaPro, using Monte Carlo simulations. Each round of the Monte Carlo simulation randomly selects values for inputs, outputs and emissions according to probability distributions. A full detailed list of all probabilities distributions and corresponding parameters is not included, since this would unnecessarily increase the length of the report. Many of the underlying processes used in the present study are documented elsewhere (e.g. Ecoinvent, Feedprint (Vellinga et al., 2013)), with the corresponding variability description.

We present here a summary of the decisions regarding probability distributions and parameters as well as specific distribution choices and parameter values when these are not reported in other publications.

- Ecoinvent processes (such as energy production, fertilizer production):
  - Ecoinvent uncertainty data were used.
- Processes modelled as aggregated processes:
  - Probability distribution information was added to inputs and emissions for a fixed output. They took the form of lognormal distributions. The geometric standard deviation was calculated based on own simulations on the Blonk Consultants database, which in turn combines Feedprint information (Vellinga et al., 2013) and own estimates. See below for more details.
- Processes modelled as unit processes:
  - Milk:
    - Feed ingredients: modelled as aggregated processes.
    - Use of nitrogen fertilizer on grass used for roughage: normal distribution with standard deviation based on a previous confidential study (Marinussen et al., 2011). For the mean amount of applied ammonium nitrate, as N, of 146 kg per ha, we estimated a standard deviation of 38.68 kg per ha, i.e., 26.5%
    - Milk yield per cow: normal distribution with standard deviation based on the same source (Marinussen et al., 2011). For the mean milk yield of the average Dutch dairy farm of 661,972 kg per year, we estimated a standard deviation of 95,538 kg, i.e., 14.4%
    - Processing of semi-skimmed milk: assumed a normal distribution with mean 0.5 and standard deviation of 0.1 around the shares of the two processing plants. This function as a proxy for variations within each of the modelled processes.
  - Cheese:
    - Similar to Milk on the common processes
    - Processing of cheese: assumed a normal distribution with mean 0.5 and standard deviation of 0.1 around the shares of the two processing plants. This function as a proxy for variations within each of the modelled processes.

For the processes modelled as aggregated processes, the parameters were estimated using Monte Carlo simulation on the database of Blonk Consultants. In these simulations the following variations were taken into account:

- Crop products: fixed inputs, and emissions, variation on the yield (normal distributions, based on Feedprint (Vellinga et al., 2013))
- Processing: variation on the energy, natural gas and auxiliary materials inputs (lognormal distributions, based on Feedprint (Vellinga et al., 2013) and on pedigree matrix where better information was lacking)

- Cooking: variation on the energy used (lognormal distribution, based on assumed variation corresponding to a geometric standard deviation of 1.2)

5.5.2 Uncertainty analysis results

Uncertainty analysis consists of calculating impacts of each system using the information about random variability in its chains. The tables bellow show the mean, standard deviation, coefficient of variation and 95% confidence interval of the distribution. The results presented below were derived from 1000 Monte Carlo runs. Table 5-4 summarizes the results for semi-skimmed milk. Table 5-5 summarizes the results for semi-cured Gouda cheese.

Table 5-4: Results of the uncertainty analysis for 1 kg of semi-skimmed milk.

Impact category	Unit	Mean	SD*	CV* (Coefficient of Variation)	2,50%*	97,50%*
Climate change	kg CO2 eq	1.13	0.133	0.117	0.909	1.44
Terrestrial acidification	kg SO2 eq	0.0216	0.00322	0.149	0.0164	0.0289
Freshwater eutrophication	kg P eq	0.00036	6.84E-05	0.19	0.000264	0.000525
Marine eutrophication	kg N eq	0.00723	0.00119	0.164	0.00524	0.0101
Agricultural land occupation	m2a	0.926	0.12	0.13	0.712	1.2
Fossil depletion	kg oil eq	0.145	0.0156	0.107	0.118	0.181

* SD: Standard Deviation; CV: Coefficient of Variation; 2,5%-97,5% = 95% confidence interval.

Table 5-5: Results of the uncertainty analysis for 1 kg of semi-cured Gouda cheese.

Impact category	Unit	Mean	SD*	CV* (Coefficient of Variation)	2,50%*	97,50%*
Climate change	kg CO2 eq	8.83	1.26	0.143	6.9	11.8
Terrestrial acidification	kg SO2 eq	0.192	0.0306	0.159	0.146	0.264
Freshwater eutrophication	kg P eq	0.00299	0.00051	0.171	0.00225	0.00425
Marine eutrophication	kg N eq	0.0652	0.0111	0.171	0.0478	0.0916
Agricultural land occupation	m2a	6.41	1.03	0.16	4.88	8.89
Fossil depletion	kg oil eq	0.857	0.114	0.133	0.678	1.13

* SD: Standard Deviation; CV: Coefficient of Variation; 95% CI: 95% confidence interval

5.6 Other studies

There are a number of other LCA studies that analyse the environmental impact of one product specifically. Schmidt & Dalgaard (2012) published a study on milk production in Sweden and Denmark. These studies have different (geographical and technological) scopes and methodologies, and may therefore not be directly comparable to this study. The study by Schmidt and Dalgaard only calculates the carbon footprint. The results of the studies and the numbers from this study are listed in Table 5-6 (showing the cradle-to-consumer impacts including packaging). To facilitate comparison, the results from this study were converted to impacts of 1 litre of milk, as this seems to be the common reference flow in the other studies.

Table 5-6: Impact on climate change for this study (for 1 kg of milk) and other studies.

	Methodology applied	Geography	Milk (kg CO_2eq)
This study	Attributional / IDF allocation	NL	1.12
This study	Attributional / economic allocation	NL	1.18
(Ecofys, 2009)	Attributional / mass allocation	NL	1.31
(Birgersson et al., 2009)	Attributional / ?	?	0.9
(Schmidt & Dalgaard, 2012)	Consequential / systems expansion	DK / SE	1.06 / 1.15
	Attributional / economic allocation	DK / SE	1.05 / 1.30
	PAS 2050	DK / SE	1.83 / 1.82
	IDF	DK / SE	1.89 / 1.72
(Thoma et al., 2012)	IDF	USA	2.05

From this table, the climate change impact for semi-skimmed milk in this study is in the same range as the other studies. The Ecofys study found a higher impact while the study by Birgersson et al. (2009) found a lower impact. The study by Schmidt & Dalgaard (2012) found a similar impact when attributional / economic allocation was applied. The study by Thoma et al. (2012) found a higher impact. The higher impact from Ecofys can potentially be explained by the choice to apply mass allocation. As other farm outputs generally have a higher economic value per unit mass, more impacts are allocated to milk. Also, some dairy cattle feed is a low value co-product from food processing, allocating on mass rather than economic value could potentially result in higher impacts from feed inputs. Unfortunately only a summary of the study was available and therefore these assertions could not be verified. Due to a lack of information on the study by Birgersson et al. (2009), the difference in impact could not be clarified. The higher impact for milk in Thoma et al. (2012) can be explained by the high wastage that was assumed (~30% loss and spoilage at consumer and retail).

5.7 Completeness check, consistency check and data quality assessment

Full details of the data sources and the accuracy of the information are detailed in the life cycle inventory. The qualitative assessment of completeness, consistency, representativeness and reproducibility are based on expert judgement of the dataset, including databases and are provided in Table 5-7. *Table 2-1* stated the minimum level of data quality that was required to be able to fulfil the study's goals, Table 5-7 assesses if these minimum requirements were met. Overall, it was considered that life cycle inventory data was complete and representative of the systems considered, and that the quality of this data was sufficient to fulfil the goal and scope of the study.

Table 5-7: Data quality requirements

Data Description	Time related coverage	Geographical coverage	Technology Coverage	Precision	Completeness	Representativeness	Consistency	Primary sources of Data	Uncertainty
Dairy cow ration composition	Current data used	Data covers regions of interest	Reflects mix of technologies	Representative for Dutch average	>90%	Reflecting Dutch average	Attributional data, economic allocation	Literature and statistics	Average
Feed cultivation and processing	Current data used	Data covers regions of interest	Reflects mix of technologies	Representative for Dutch average	>95%	Reflecting Dutch average	Attributional data, economic allocation, ipcc calcution framework	Previous studies	Average
Dairy farm processes	Current data used	Data covers regions of interest	Reflects mix of technologies	Representative for Dutch average Good	>95%	Reflecting Dutch average	Attributional data, economic allocation	Literature and statistics	Average
Energy supply	Current data used	Data covers regions of interest	Reflects mix of technologies	Representative for Dutch average	>95%	Reflecting Dutch average	Attributional data, economic allocation	Background dataset	Average
Milk manufacturing processes	Current data used	Data covers regions of interest	Specific manufacturer	Specific to manufacturer process	>95%	FrieslandCampina's processes	Attributional data, economic allocation	Manufacturer data	Average
Cheese manufacturing processes	Current data used	Data covers regions of interest	Specific manufacturer	Specific to manufacturer process	>95%	FrieslandCampina's processes	Attributional data, economic allocation	Manufacturer data	Average
Packaging	Current data used	Data covers regions of interest	Specific manufacturer	Specific packaging formats considered	>95%	Reflecting typical packaging	Attributional data, economic allocation	Manufacturer/Background data	Average

From comparing Table 5-7 with *Table 2-1*, it can be understood that not all data requirements were strictly met. All data has been consistently modelled using an attributional approach, however allocation choices may differ between background datasets (e.g. some may use a biophysical allocation methodology while others are based on economic information). The data on feed cultivation did originally not cover all the relevant impact categories. However, these LCIs have been extended to incorporate additional flows of relevance (e.g. ammonia and nitrate emissions). Capital equipment in these processes has however been omitted. A study (Frischknecht et al., 2007) indicates that capital equipment could be of importance for agricultural processes impacts, however this seems to apply only to impact categories that were beyond the scope of the study, and therefore this omission does not affect the quality of the data. These inventories are therefore considered to be sufficiently complete (>95%). Capital equipment is included in the background processes from Ecoinvent, this increases the completeness of these processes but can be seen as a slight inconsistency. Overall, it can be concluded that the study is sufficiently complete (overall at least 95% of data has been modelled) and consistent (all data is modelled using similar methodologies) and the overall data quality is sufficient to support the study results and conclusions.

6 Discussion

The drivers of the impacts have been investigated in the previous sections (5.1-5.3) as well as how the results are potentially affected by modelling assumptions (5.4) and data uncertainty (5.5), also how the results compare to other LCA studies' results has been analysed (5.6). This section summarises the outcomes of these sections and emphasises the key issues.

The impacts for semi-skimmed milk are mainly determined by processes that happen on the dairy farm. In particular, emissions associated with enteric fermentation and manure management have a large impact on climate change, terrestrial acidification, freshwater and marine eutrophication. These impacts could potentially be reduced by improved manure management and reduction of enteric methane emissions through feed optimization or the use of special feed additives. The improvement potentials were outside the scope of this study and can therefore not yet be quantified.

Land use affects a number of environmental themes including biodiversity and climate change. Unfortunately, there is no consensus on how to account for these impacts of land use. For example, both ILCD and ReCiPe (endpoint) look at the impact of land use on biodiversity using different approaches and reaching different conclusions. There is also no consensus on the best method to calculate climate change induced by LUC, which is why the impact of LUC is reported separately. The impact on climate change rises with 7% to 24% when taking LUC into account, depending on the method used for calculating the impact of LUC on climate change.

The LCI modelling frameworks are not clear on which approach should be chosen for allocation. This is the reason why two regularly applied allocation approaches have been investigated in this analysis. The allocation rules chosen for the dairy farm has an impact on the results. Between the IDF allocation and economic allocation the environmental impact shifts about 5% for semi-skimmed milk.

7 Conclusions

1. An uncertainty analysis has been done calculating impacts of each system using the information about random variability in its chains.
    a. For semi-skimmed milk and semi-cured cheese the impact on climate change ranges from 0.91 to 1.44 kg CO_2eq/kg and 6.9 to 11.8 kg CO_2eq/kg respectively (95% confidence interval).
    b. For semi-skimmed milk and semi-cured cheese the impact on agricultural land occupation ranges from 0.71 to 1.2 m^2a/kg and 4.88 to 8.89 m^2a/kg respectively (95% confidence interval).
    c. For semi-skimmed milk and semi-cured cheese the impact on fossil depletion ranges from 0.12 to 0.18 kg oil eq/kg and 0.68 to 1.13 kg oil eq/kg respectively (95% confidence interval).

2. Impacts from land use change are not considered in the baseline scenarios and were only explored for the dairy products and the main substitutes, however if the impact from land use change (LUC) on climate change is included, the impacts of all systems increase.
    a. For semi-skimmed milk the impact on climate change increases by 7-21% (depending on the applied method).
    b. For semi-mature cheese, the impact on climate change increases by 8-24% (depending on the applied method).

3. The IDF allocation method was applied for the farm products (raw milk, meat and live animals). If economic allocation would be applied, the impact for semi-skimmed milk would increase (by +/- 5%).

7.1 Study limitations

1. The LCI data for production and composition of milk and cheese were obtained from a limited amount of producers. We assume that these are representative for similar products available on the Dutch market.

2. LUC is not part of the main report, but only explored in the sensitivity analysis for the dairy products and the main substitutes.

3. Capital equipment has not been included in processes related to feed and food cultivation and processing, but has been included in background processes (for example, related to transport and energy production). The environmental impacts could increase if capital equipment were included.

4. No impact category on midpoint level dealing with water/water scarcity was analysed. Some of the analysed products were cultivated in water scarce areas.

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Appendix A. The review process

During the review of the draft report the critical review panel identified the following points as most critical. In this annex **Blonk Consultants** explains how we have addressed each of these issues. The points which do not apply to the revision of the original report have been deleted.

1. *Transparency: in many cases the provided descriptions and data have not allowed for checking/reviewing the calculations. Examples are calculation of CH4 from enteric fermentation and manure management, field emissions (N2O, NH3 etc.), LUC emissions.*

   Blonk Consultants: together with the panel we identified the important issues regarding transparency. We added data on CH4 from enteric fermentation per litre of milk. Also we added a table with yields and fertilizer use for the most important crops in compound feed. A table with all products in the optimization tool with their ReCiPe score was added to the annexes.

2. *An attributional modelling approach has been chosen. In practice this means that multiple-output processes are modelled using allocation. According to ISO 14044, this way of modelling shall/should be avoided whenever possible. Justification is needed:*
   - *The current justification of the choice of allocation instead of substitution is not sufficient.*
   - *A justification that the choice of modelling approach does not affect the overall conclusions of the study is needed.*

   Blonk Consultants: as a justification for our choice of allocation, we agreed with the panel to add a reference to the ILCD handbook, where it is mentioned that allocation is allowed in cases of high complexity. Another reason to choose for allocation is lack of data both in generic background data and databases. We also mention two exceptions: manure applied outside the dairy farm (no economic value) and waste incineration (avoided natural gas and electricity).

3. *An evaluation of sensitivity, completeness and consistency is missing in the interpretation phase. According to ISO 14044 (section 4.5.3) this is required.*

   Blonk Consultants: this section was indeed lacking in the draft report even though it is an ISO requirement. Therefore we added this section to the final report.

Appendix B. Final review statement

The points which do not apply to the revision of the original report have been deleted. See next page.

Critical panel review report: Comparative LCA of Dutch dairy products and plant-based alternatives

Review panel and review procedure

Review panel:

This review report contains review comments from the following reviewers:

- *Jannick Hoejrup Schmidt, 2.-0 LCA consultants, Denmark (chair person of the review panel)*
- *Fausto Freire, Universidade de Coimbra, Portugal*
- *Toni Meier, Martin-Luther-University Halle-Wittenberg, Germany*
- *Imke de Boer, Wageningen UR, the Netherlands*

Review statement on the following LCA report:

Comparative LCA of Dutch dairy products and plant-based alternatives
– Main report

ISO 14040/44 on critical review of LCA

This critical panel review is carried out in accordance with ISO 14040/44.

The current LCA has the following characteristics which mean that ISO 14044 defines some additional requirements to the study as well as the critical review:

- The study is a third party report (ISO 14044, section 5.2)
- The study is a study where the results are intended to be used to support a comparative assertion intended to be disclosed to the public (ISO 14044, section 5.3)

As a consequence of the above mentioned characteristics of the study, the main additional requirements are:

- ISO 14044, section 4.4.5: Requirements for the LCIA for comparative assertion intended to be disclosed to the public
- ISO 14044, section 5.2: Additional requirements and guidance for third party reports
- ISO 14044, section 5.3: Further reporting requirements for comparative assertion intended to be disclosed to the public
- ISO 14044, section 6.1: A panel of interested parties shall conduct the critical review

Review procedure:

- Preliminary review of goal and scope report: The review panel has reviewed a draft version of the goal and scope report received on 18th of January 2013, and provided preliminary inputs to the study on 1st of February 2013.
- Bilateral: Discussions on LUC between LCA practitioner and some reviewers to provide preliminary input to the study.

- Panel review report: Based on a final draft of the LCA report received 28th of June 2013, the four reviewers have provided their comments on the study on 5th of July 2013.
- Based on the responses by the LCA practitioner to the comments raised in the current review report, a final review statement was agreed upon among the review panel. This was provided to the LCA practitioner on 20th of September 2013.

Overall critical review statement (preliminary draft)

It is assessed that the reviewed LCA study is generally in compliance with the ISO 14040/44 standard on LCA. However, the following issues in the study deviate from the requirements and recommendations in ISO:

- **Multiple-output processes:** According to ISO 14044 (section 4.3.4.2), allocation shall be dealt with by the following procedure (the review panel has reworded/shortened the original ISO-text):
    - Step 1) Wherever possible, allocation should be avoided by dividing the unit process or expanding the product system to include the additional functions related to the co-products
    - Step 2) Allocate inputs and outputs of the system in a way that reflects the underlying physical relationships between them
    - Step 3) Allocate inputs and outputs of the system using other relationships

  ISO step (1) has only been applied for waste incineration, whereas step (3) has been used for other co-products; generally economic allocation is used – except for exported manure where all downstream environmental impacts are allocated to the crops on which the manure is applied. Justification for the adopted approach is provided. However, one of the arguments is that it is too complex to apply substitution – the validity of this argument is questionable; a) other studies on milk where allocation is avoided by substitution exist, b) the determination of consistent points of allocation and subsequent calculations are probably more complex than substitution, and c) allocation alters mass balances (e.g. economic allocation implies that the inputs and outputs of allocated processes do not balance), and ensuring fundamental mass balances in an allocated system is an additional source of complexity.
- **Included impact categories**: According to ISO 14044 (section 4.4.2.2): "*The selection of impact categories … shall be both justified and consistent with the goal of the study*" and "*The selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration.*". In the study the ReCiPe LCIA method is used. It was chosen to exclude the following impact categories: ozone depletion, toxicity categories, photochemical oxidant formation, particulate matter, ionising radiation, urban land occupation, water and metal depletion. The following problems with regard to ISO 14044 compliance are identified:
    - The goal of the study is not limited to the included impact categories – the goal of the study refers to "the environmental impact".

- Justification for the exclusion of toxicity categories is provided – but for the other impact categories the only justification is “Wish of the commissioner”. This is not regarded as sufficient.
- The conclusions of the LCA do not address the fact that potentially important impact categories are excluded from the results.

Besides the issues above which refer to strict ISO compliance, the review panel has the follow comment on the study:

- **Land use changes (LUC):** LUC-emissions are not included in the default calculations, but the contribution from LUC is assessed in a sensitivity analysis. The uncertainties related to the different LUC models are substantial but not mentioned in the study. Especially for the PAS2050 and the UNEP-SETAC methods, the contribution from LUC is highly dependent of the source of the crops due to the 20 years depreciation period. These uncertainties should be mentioned along with the selection of methods, in the sensitivity analysis and in the conclusion where reference is made to the LUC sensitivity analysis.

Appendix C. Response to reviewer comments

Response of Blonk Consultants to the "Overall critical review statement".

In its final review statement the critical review panel states that the study is generally in agreement with ISO, but mentions two issues where the study deviates from requirements and recommendations in ISO. Below Blonk Consultants briefly gives its opinion on these issues:

- **Multiple output processes**

  The selection of the most appropriate allocation method remains debatable, since ISO 14044 applies a sequence of options but gives no clear guidance on when a next step is desirable.
  With regard to the option to apply substitution in the dairy system, we are aware of the LCA publications that are available for dairy systems. We do not agree however with the selected marginal processes that are used to model (changes) in feed. We are currently exploring this matter together with the feed industry as part of a study on how to apply LCA when shifts in feed materials are being studied.
  Regarding the mass balance issue we would like to stress that in our LCA model all co-production processes are balanced (both in energy and mass) and are not split in sub processes. In this way the mass balances are not lost by applying economic allocation.

- **Included impact categories**
  As the reviewers state the argumentation for selection of impact categories could have been more comprehensive. Now some impact categories seem to be excluded without any or (too) little argumentation. So the goal environmental impact assessment might be a too broad qualification and a remark in the conclusions on the exclusion of potentially important categories would have been appropriate.

  ISO 14044 sets several requirements and gives a lot of guidelines for impact assessment, but it does not provide a list of impact categories that shall be included. Since we started reasoning from a defined set of impact categories (ReCiPe) and excluded several impacts it might give the impression that we have a narrow set. However, if you compare the list of remaining impact categories with recently reviewed ISO compliant LCAs the list is not so small.

  Furthermore it is good to realize that the set of impact categories which needs to be applied in food LCAs is now extensively debated in several big international projects on developing Product Category Rules (ENVIFOOD) and LCA Guidelines (FAO-LEAP) for food products. The outcome is not clear yet, but it seems that a limited set of 6 or 7 impact categories/ indicators will be identified as mandatory to include. These are probably GHG emissions (plus direct LUC), fossil energy use, mineral depletion, acidification, eutrophication (at several levels), land occupation and water use. Except for water use, all these impacts/indicators were included in this comparative LCA. Some others are good to explore but are less relevant or give major data problems (e.g. ecotoxicity in relation to pesticides use)
  It should also be stressed that the LCA methodology lacks some key impact categories which should be further developed within short notice, such as soil degradation, salinisation and depletion of marine resources.

In addition to the issues related to ISO compliance, the panel made three comments on the study. We have no additional comments regarding the intended application/decision context of the study and the robustness. In general, we agree.
With respect to GHG emissions due to Land Use Change (LUC) we agree that the uncertainty of the underlying data is not further explored. We consider this as an additional uncertain impact that should be reported separately. Since we do not build any conclusion on the results, a further exploration of uncertainty seems not essential.