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Life cycle assessment of Romanian beef and dairy products

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Glossary and Acronyms

CIP	Clean-In-Place
FAO	Food and Agriculture organisation
FU	Functional Unit
GWP	global warming potential
IPCC	Intergovernmental panel of climate change
HDPE	high-density Polyethylene
IDF	International Dairy Federation
KEPI	Key environmental performance indicator
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LCI	Life cycle inventory analysis
LDPE	low-density Polyethylene
LLDPE	linear low-density polyethylene
MSWI	Municipal Solid Waste Incinerator
PET	polyethylene terephthalate
SENSE	Harmonised Environmental Sustainability in the European food and drink chain
SME	small and medium enterprises

EXECUTIVE SUMMARY

This case study investigates a cradle-to-gate life cycle assessment (LCA) of the production of beef and dairy products in Romania. The distribution and selling by retailers as well as the food preparation in industry and consumption at household are not part of the assessment. The functional units assessed are one kg of beef at slaughterhouse and one kg of dairy product at dairy plant including their packaging. The dairy products assessed are pasteurized milk, sour cream, natural yoghurt, curd, butter, cream cheese, fresh cheese, soft cheese and semi-soft cheese.

The goal of these two LCAs is to identify the priority information that should be asked from an SME, e.g. a dairy farm, a slaughterhouse or a dairy plant, in order to assess its environmental performance. A list of key environmental performance indicators (KEPIs) is the first outcome of this case study. The second outcome of the study is the identification of some regionalisation potentials in order to account for some regional characteristics within European dairy farms.

The assessment is valid for Romania. Data were collected from a dairy farm, a slaughterhouse and a dairy plant in this country. All foreground data refers to 2011. The allocation for meat and milk at the dairy farm follows the physical allocation approach suggested by the international dairy federation (IDF 2010). The allocation for the meat produced at the slaughterhouse follows an economical approach. The allocation for the dairy products at the dairy plant follows a physico-chemical approach suggested by IDF (2010) and an alternative scenario based on fat content and economic turnover.

The impact assessment is done using midpoint impact assessment methods defined in WP1 of the SENSE project (Aronsson et al. 2013). Indicators for climate change, eutrophication, acidification, human toxicity, ecotoxicity, land use, abiotic resource depletion and water depletion are included in the assessment.

The impact assessment of the beef shows that the feed production at the dairy farm is the main contributor to the results. The slaughtering process and the packaging are negligible to most of the impact categories. The emissions from the use of fertilisers, manure and diesel for the agricultural machinery influence the results most. The cattle emissions due to the enteric fermentation are the main source for the climate change. The animal waste disposal from slaughtering is also an important step due to its processing into animal flour before its incineration.

The impact assessment of the dairy products is similar to the beef because raw milk is produced by the dairy cows. The dairy farm is also the most important step to most of the dairy products. However, the contribution of the processing step to the production of dairy products is higher than the contribution of the slaughtering process to the beef production. For example, the processing of raw milk into yoghurt is an energy-intensive process. The Romanian electricity mix relies on lignite as a fossil fuel and its combustion affects the climate change and the abiotic resource depletion.

The key environmental performance indicators are proposed as simple to measure indicators that can be used in the SENSE tool to calculate the environmental impacts in future case studies. The KEPIs identified for the production of beef and dairy products are shown in Table 1.1. They are identified for each production step: fodder production, livestock, milking, slaughtering and dairy processing and each impact category. The table shows also the main pollutants concerning a specific impact category and influenced by a specific KEPI. Our case study fodder was produced on the same farm as the animals. If animal feed is bought on the market the relevant KEPIs have to be investigated for the production of all the different type of feed bought by the farm, e.g. soy bean, maize, by-products of food and bioenergy production etc.

Table 1.1 KEPIs for the production of beef and dairy products

Impact category	Fodder production									Livestock							Milking		Slaughtering		Dairy processing					Main pollutants
Unit	kg-N/ha	kg-P2O5/ha	kg/ha	kg/ha	l/ha	ha	ha	m3/ha	m2	number and categories	kg live weight/category	kg raw milk/dairy cow	%	%	kg feed/kg live weight	number/category	kWh/kg raw milk	m3/ kg raw milk	kg meat/kg live weight	kg waste/kg meat	kg raw milk/kg product	kg product /category	MJ/kg raw milk	kg/kg product	m3/ kg raw milk	
Key Environmental Performance Indicator (KEPI)	N-fertiliser use	P2O5-fertiliser use	Manure and slurry application	Pesticide and active substance content	Diesel use incl. machineries	Arable land use	Grazing land use	Water use	Buildings	Herd size	Cattle weight	Raw milk production	Raw milk fat content	Raw milk protein content	Feed efficiency	Cattle to slaughtering	Electricity use milking	Water use milking	Meat production	Waste	Raw milk input	Dairy products	Thermal energy	Packaging material	Water use	
All impact categories										x	x	x	x	x	x	x			x	x	x	x				
Climate change	N2O		N2O		CO2					CH4							CO2						CO2	CO2		CO2, CH4, N2O
Human toxicity		HM			HM				HM																	Heavy metals (HM)
Acidification	NH3		NH3		NOx					NH3																NOx, NH3
Eutrophication, terrestrial	NOx		NH3		NOx					NH3																NO3, NH3
Eutrophication, freshwater		PO4		PPP	PO4	PO4	PO4																			PO4
Eutrophication, marine	NO3		NO3		NOx																					NO3 (Nitrate), NOx
Ecotoxicity, freshwater		HM		PPP	HM																					Heavy metals (HM) Plant Protection Products (PPP)
Land use						x	x																			Land use (m2a and type)
Abiotic resource depletion	x	x		x	x				x								x						x	x		Fossil resources (oil, gas, coal)
Water depletion					x			x										x							x	Water use

The allocation approach for the milk and beef at farm applied in this case study is also recommended for the SENSE tool. It is also suggested to fully allocate the resource use ad the emissions to the beef produced at the slaughterhouse and none to the by-products. Regarding the resource use and emissions at the dairy plant, some uncertainties arise from the allocation matrix provided by the IDF. The matrix is a starting point and need to be further developed. Some allocation factors were missing to differentiate all the dairy products and some were used for more than one dairy product. Some allocation factors are also missing for infrastructure and an economic allocation was applied in these cases. Additional organic inputs (milk protein, lyophilized cultures) were allocated based on a mass allocation. It might be simpler for the SENSE tool to combine a dry mass allocation approach for the raw milk input and an economic allocation for the other resources use, i.e. electricity, natural gas, water etc. than to use the IDF approach.

An important question of the project is the adjustment of the SENSE model to regional characteristics. Since data are publicly available on country-specific electricity mix and there might be considerable differences in the environmental impacts, it is recommended to implement country-specific electricity mix in the SENSE tool. It is also recommended to regionalise water depletion, acidification and terrestrial eutrophication impact assessment methods since country-specific characterisation factors are already available. The regionalisation of emissions models was only implemented for the livestock methane emissions factors by using IPCC guidelines. Easy-to-apply models for European regions are so far not available in order to regionalise other emission models.

1 Introduction

The food and drink industry in Europe, of which 99% are small and medium enterprises, is highly fragmented, and food chains are very complex. Hence, to assess the environmental sustainability of a product there is a need for applying integrated, harmonised and scientifically robust methodologies, together with appropriate communication strategies for making environmental sustainability understandable to the market. However, there are difficulties in developing a commonly agreed methodology for environmental impact assessment that still need to be overcome. Challenges are the complexity of food chains, the large number of agents involved, different suitable environmental indicators depending on the business sector, regional differences related to biodiversity among other challenges, including climate change and complexity of the current sustainability assessment tools - high data intensity, costs and expertise required.

The European research project SENSE aims to deliver a harmonised system for the environmental impact assessment of food and drink products. The research evaluates existing relevant environmental impact assessment methodologies, and considers socio-economical, quality and safety aspects, to deliver a new integral system that can be linked to monitoring and traceability data. The system will integrate:

(a) (regionalised) data gathering system;

(b) matrix of key environmental performance indicators;

(c) methodology for environmental impact assessment; and

(d) a certification scheme.

The methodology will be transferred to food & drink sectors and stakeholders by means of specific communication strategies.

The sustainability information collected along the supply chain of any food stuff and reflected into the EID (Environmental Identification Document) will be accessible by the EID-Communication Platform. This should contribute to making the environmental sustainability part of the usual purchasing behaviour of consumers and provide a competitive advantage to those products (and companies) which choose to use the EID. Through a comprehensive environmental communication between the industry and consumers the latter are empowered to choose food products which are environmentally friendly.

2 Outline of the LCA Studies

2.1 Overview

Task 2.1 of the SENSE project investigates current food production and supply systems from a regional perspective. According to the methodology developed in WP1, three Life Cycle Assessment (LCA) case studies are performed. The followings selected food chains are studied:

- dairy & beef production in Romania
- orange juice production in Spain (separate report)
- fish aquaculture in Norway (separate report)

The goal of Task 2.1 is to propose a selection of key attributes and suitable scope of essential input data based on LCA results interpretation and sensitivity analysis. The required information for the LCA (e.g. water, energy, materials consumption) shall be prioritised according to the most important environmental impacts. Moreover, a set of allocation rules for the selected food chains is to be addressed.

Thus, a systematic overview of the life cycle of food and drink products and their environmental impacts associated is to be presented, taking into account the diversity within this sector in the different regions across the European market. This will provide the SENSE framework to overcome the variations in the environmental approaches of companies that produce similar products in different regions.

2.2 System boundaries

The gate of all LCA case studies is the last production stage with the distribution packaging included. The distribution and selling by retailers as well as the food preparation and consumption at household or in restaurants is not part of the assessment.

2.3 Questions to be answered

The following questions shall be addressed by these case studies:

- What are the most relevant stages in the life cycle?
- What are the key environmental performance indicators (KEPIs) to be requested in the SENSE tool?
- How are the results affected by regional background data?
- How do regional emission models affect the results?
- How are the results affected by a regionalised impact assessment?
- What are the recommendations regarding the allocation rules?
- Which system boundaries shall be applied in the SENSE tool?

2.4 Inventory basic assumptions

The LCI methodology follows in many aspects the methodology applied to the ecoinvent background data (Frischknecht et al. 2007). The following main assumptions are considered:

- Standard distances are used for the transport of materials from their production site to the processing plant or farm They are all ecoinvent transport unit processes (Nemecek et al. 2007). It includes 10 km van, 70 km lorry 25 t and 30 km train.

- Infrastructure is included with a life time of 50 years and a construction time of 2 years
- The name of pesticide and the amount active ingredient applied are used to model the environmental fate in the inventory. The environmental fate is assumed to be 100 % to soil. This statement follows the code of life cycle inventory practice (de Beaufort-Langeveld et al. 2003) which is also applied in the ecoinvent background data.
- Waste management is included
- Recycling processes are not included (cut-off approach)
- Country specific datasets for electricity and tap water are used

2.5 Impact Assessment Methods

The midpoint impact categories applied in the SENSE project for the LCA case studies of three food chains are the following (Aronsson et al. 2013). Long-term emissions are excluded from the assessment. Since there are midpoints categories, no endpoints results are computed.

Table 2.1 Midpoint impact categories chosen for the SENSE project (Aronsson et al. 2013)

Impact category	Methods	Indicator unit
Climate change	Bern Model – IPCC, 2007	kg CO_2 eq
Human toxicity	USEtox Model (Rosembaum et al, 2008)	CTUh (Comparative Toxic unit for humans)
Acidification	Accumulated Exceedance (Seppälä et al, 2006, Posch et al, 2008) *Regionalised at country level for Europe*	molc H+ eq
Eutrophication, terrestrial	Accumulated Exceedance (Seppälä et al, 2006, Posch et al, 2008) *Regionalised at country level for Europe*	molc N eq
Eutrophication, freshwater	EUTREND Model (Struijs et al 2009b) as implemented in ReCipe	Freshwater: kg P eq Marine: kg N eq
Eutrophication, marine	EUTREND Model (Struijs et al 2009b) as implemented in ReCipe	kg N eq
Ecotoxicity, freshwater	USEtox Model (Rosembaum et al, 2008)	CTUe (Comparative Toxic Unit for ecosystems)
Land use	Soil Organic Matter model (Milà I Canals et al, 2007b)	kg C deficit
Abiotic resource depletion	CML 2002 (Guinée et al, 2002)	kg antimony (Sb) eq
Water depletion	Ecological scarcity model (Frischknecht et al. 2009) *Regionalised at country level for Europe*	European m^3 water eq

2.6 Key Environmental Performance Indicators (KEPI)

The goal of the SENSE project is to develop an internet tool for SME's (small and medium enterprises) in the food sector. In order to assess their environmental performance, SME's should enter some data that will be used to calculate the environmental impacts as accurate as possible in a simplified way. Through the three case studies elaborated in this project and with a literature review on existing LCA studies (Landquist et al. 2013), the key data that the SME's have to provide are identified. These key data are named as key environmental performance indicators (KEPIs). They should be easy-to-measure indicators that can be provided by the operators of farms and food industries.

3 Life Cycle Assessment of Beef and Dairy products

3.1 Goal and Scope

3.1.1 Object of Investigation

This case study investigates a cradle-to-gate life cycle assessment of the production of beef and dairy products in Romania.

3.1.2 Functional Units

The functional units (FU) are defined as "**one kg of bone-free beef at slaughterhouse**" and "**one kg of Romanian dairy product at dairy**". The considered dairy products are illustrated in Table 3.1: The packaging is included in both functional units.

Table 3.1 Dairy products assessed at the dairy plant

FU	Packaging included in FU
Pasteurized milk	PE bottle
Sour cream	Polystyrene cup with aluminium lidding
Yoghurt natural	Polystyrene cup with aluminium lidding
Curd	Polystyrene cup with aluminium lidding
Butter	3-layers packaging (aluminium, synthetic wax, paper)
Fresh cheese	Polystyrene cup with aluminium lidding
Cream cheese	Polystyrene cup with aluminium lidding
Soft cheese	Plastic foil
Semi-soft cheese	Plastic foil

3.1.3 System Boundaries

The life cycle inventory of beef and dairy products encompasses the whole supply chain starting with the cultivation of animal feed and ending with the beef at the slaughterhouse and the dairy products at the dairy plant. A model of the production system is shown in Figure 3-1. At the dairy farm, cows give birth to calves in order to produce milk. They are called dairy cows. Calves are reared to become dairy cows or bulls. At the end of their life, dairy cows, or usually called cull dairy cows, are removed from the milk production herd and are sent to the slaughterhouse along with bulls to be processed into beef. The raw milk produced by dairy cows is sent to the dairy farm for processing into pasteurized milk, yoghurt, cheese, butter and cream. Therefore, the life cycle includes the dairy farm, the slaughterhouse and the dairy plant.

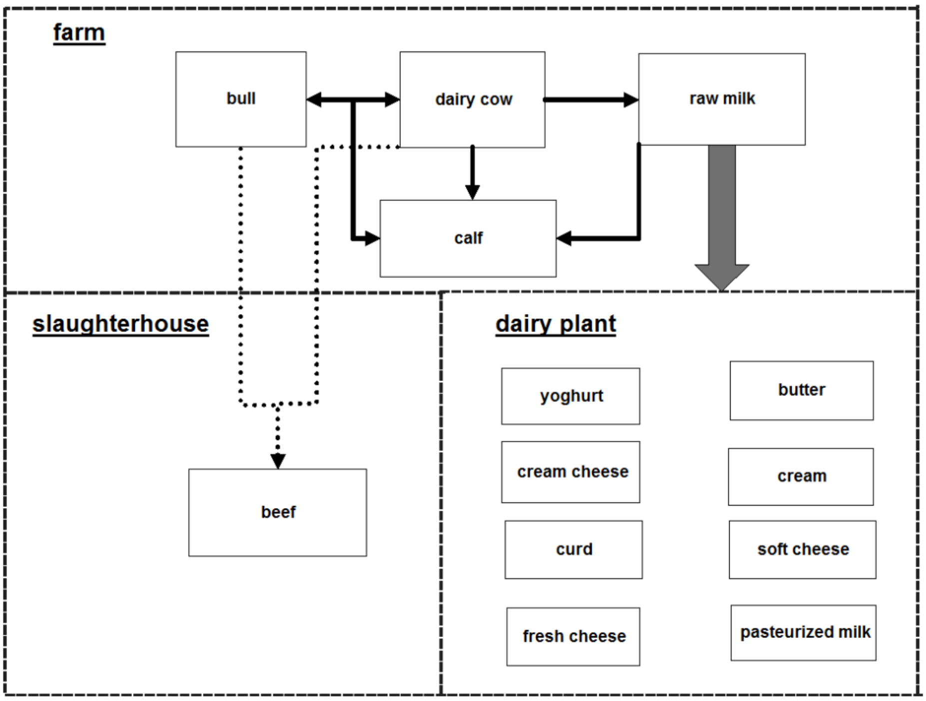

Figure 3-1 Product system of beef and dairy products in this study

3.1.4 Main Data Sources

Provac Impex SRL, partner in SENSE project, provided foreground inventory data for the dairy farm. Calion Prod SRL[1] provided the inventory data for the dairy plant and Agro-invest Prod SRL[2] provided the inventory data for the slaughterhouse. The data refer to the reference year 2011. Foreground data include

- Quantities of materials, energy used for the operation of the dairy farm.
- Quantities of materials and energy used for the operation of the slaughterhouse
- Quantities of materials and energy used for the operation of the dairy plant.
- Economic value and share of turnover for different products.

Incomplete foreground data are completed using literature data as well as data from the database of ESU-services ltd. (Jungbluth et al. 2013).

The primary source of background inventory data used in this study is the ecoinvent data v2.2 (ecoinvent Centre 2010), which contains inventory data of many basic materials, energy carriers, waste management and transport services. Further and updated data from public available datasets are used (LC-inventories 2013).

[1] http://www.calion.ro
[2] http://www.agro-invest.ro/

3.1.5 Allocation

The operation of a dairy farm, the operation of a slaughterhouse and the operation of a dairy plant are multi-output processes with a range of output products. However, inputs such as resource use and energy consumption and outputs such as emissions and wastes are most of the time provided on a factory basis and not separately for each output product. In order to allocate inputs and outputs to each output products, allocation rules have to be applied where no direct physical relation can be identified.

The dairy farm produces milk from dairy cows and also generates meat from the cull dairy cows and bulls as shown in Figure 3-1. The resource use, energy consumption and emissions due to the animal feed production at the farm must be allocated to each output product. The allocation factor for meat and milk is computed using the guidelines from the International Dairy Federation (IDF 2010). The guidelines follow a physical allocation approach based on the differences in the feed conversion to milk and meat, " a causal relationship between the energy content in the animal ration and milk and beef production was developed. In short, feed energy available for growth, for a given feed, is lower than that available for milk production. The conversion of feed to milk is more efficient use of the feed".[3]

The Romanian slaughterhouse slaughters pigs and cattle. The output products of the slaughtering process are pork, beef and cattle skin. Energy use, waste and other inputs of the slaughterhouse are allocated to the output products using an economic allocation approach based on the product's shares in turnover in 2011.

The dairy plant processes raw milk into pasteurized milk, yoghurt, sour cream, curd, fresh cheese, cream cheese, soft cheese and semi-soft cheese. Data in the questionnaire were given on a whole of factory basis. The IDF provides a matrix of allocation coefficients, which are based on a physico-chemical allocation approach. Allocation factors are provided for electricity, raw milk, raw milk transport, water use, fuel for thermal energy, cleaners and wastewater. The range of dairy products assessed in the IDF matrix is however smaller than the dairy products at the Romanian dairy. Therefore, the same allocation factors are taken for semi-soft cheese and soft cheese. Similarly, the same allocation factors are applied to yoghurt, curd, fresh cheese and yoghurt cheese. The reason is that the fat content of these products are in the same range. The building infrastructure is allocated based on the shares in turnover of each dairy product and the additional inputs such as milk protein, lyophilized cultures and calcium chloride are allocated based on the total mass of the products for which they are used. For example, milk protein is added to yoghurt and sour cream so it is allocated based on the total output mass of these two products.

3.1.6 Modelling process

The output products of the operation of the dairy farm are the following:

1. Cull dairy cows and bulls, at dairy farm (kg)
2. Raw milk, at dairy farm (kg)
3. Suckler cow, at dairy farm (kg)
4. Calf, at dairy farm (kg)

3.1.7 Scenarios

So far no scenarios are investigated for this case study.

[3] IDF 2010 Appendix B p.35

3.2 Life Cycle Inventory Analysis

In the following an overview of the life cycle inventory analysis (LCI) is presented. The full LCI is documented in a confidential annexe to this report, which is only available for the partners in the project consortium.

3.2.1 Dairy farm

Key figures

The life cycle inventory of the farm was obtained from a questionnaire filled in by the Romanian farm SC Provac Impex SRL and further communication with the responsible persons. The key figures of the dairy farm are shown in Table 3.2. All data refer to the year 2011. The main purpose of the farm is to produce milk so it is called a "dairy farm" in the report.

The dairy farm had 60 dairy cows, 22 bulls, 30 suckler cows and 40 calves are born each year in average. The farm purchases seeds and cultivates its own animal feed (maize silage, wheat, barley, oat, alfalfa). The dinitrogen oxide emissions to air from crop residues are included in the inventory, following the IPCC guidelines (De Klein et al. 2006). The grazing land and the land occupied by the crop cultivation are included in the inventory. The emissions of phosphorus to water due to leaching, run-off and soil erosion are also included in the inventory, following ecoinvent guidelines (Nemecek et al. 2007). The emissions are independent from the manure and fertilisers applied, which are considered in the dataset on manure and fertilisers.

The animal feed is high quality forage and animals are fed in stall with the additional use of mineral feed and cattle salt. Cattle at farm produce organic fertilisers such as manure and slurry. Manure is stored in a dry lot (paved or unpaved open confinement area without any significant vegetative cover) and 40 tons per hectare are applied to fields each three years. Liquid manure (approx. 10% of the total) is collected in underground collecting tanks and 10 tons per hectare (diluted 50%) are applied each three years. The emissions to air of ammonia (NH_3), dinitrogen oxide (N_2O) and nitrogen oxides (NOx) and emissions to water of phosphate (PO_4) and nitrate (NO_3) are included in the inventory based on Nemecek (2007) and the IPCC guidelines in Hongmin (2006).

The dairy farm fertilises its soil by applying N-fertiliser and P_2O_5-fertiliser. Their production and transport to the dairy farm are included in the inventory. The use N-fertiliser causes emissions to air, e.g. ammonia, dinitrogen oxide and nitrogen oxides, and emissions to air, e.g. nitrate. The use of P_2O_5-fertiliser generates emissions of phosphate to water and emissions of element content to soil, following guidelines from Nemecek (2007) and the IPCC guidelines in Hongmin (2006).

Crops are protected with the application of herbicides. No insecticides or fungicides are used at the Romanian dairy farm. Their transport to the dairy farm is included. The identification of the active ingredient contained in each herbicide is necessary to model the emissions into soil.

The machineries (tractor, tillage, harvester, trailer) used for the crop cultivation, fertiliser and manure application consume diesel. The diesel used is modelled with a dataset that includes the fuel consumption and its emissions into air resulting from the combustion as well as the amount of agricultural machinery manufactured and the emissions into soil caused by the tyre abrasion.

During the digestive process, i.e. enteric fermentation, cattle produce methane. The methane emission factors were computed following the IPCC guidelines on livestock emissions (Hongmin et al. 2006). When the animals are confined in stall, the emissions from excrement are directly emitted into air. These ammonia emissions are taken from Alig (2012) and Jungbluth (2000) for the calf.

Table 3.2 Key figures of the dairy farm operation in yearly amounts 2011

Land use		Year 2011	Per hectare cultivated area
Land use, cultivated area	m2	895000	1
Land use, graze land	m2	720000	-
Water use			
Groundwater use	m3	1000	
Wastewater	m3	1000	
Buildings			
Cattle housing and storehouse	m2	2180	--
Office	m3	500	--
Organic and chemical fertilisers			
N-fertiliser	Kg-N	1080	12.1
P2O5-fertiliser	Kg-P2O5	1832	20.5
Manure	kg	800000	13333
Liquid manure	m^3	144	1.67
Herbicide			
Total amount of herbicide use	kg	28	0.31
Active substance emissions into soil from herbicide use			
2,4-D	kg	27.2	0.30
Rimsulfuron	kg	0.5	0.006
Thifensulfuron-methyl	kg	0.42	0.005
Agricultural machinery			
Diesel, used by tractor	kg	16380	183
Cattle emissions			**Per animal**
Dairy cow	#/a	60	1
Enteric fermentation	kg CH_4/a	6300	105
Ammonia emissions in open yard	kg NH_3/a	163	5.8
Bull	#/a	22	1
Enteric fermentation	kg CH_4/a	1470	67
Ammonia emissions in open yard	kg NH_3/a	60	2.7
Suckler cow	#/a	30	1
Enteric fermentation	kg CH_4/a	2485	83
Ammonia emissions in open yard	kg NH_3/a	174	5.8
Calf	#/a	40	1
Enteric fermentation	kg CH_4/a	1227	27
Ammonia emissions in open yard	kg NH_3/a	40	1
Milking			**Per kg raw milk**
Electricity use for milking	kWh	16260	0.06
Refrigerant use: Freon	kg	5.0	0.000018
Milk losses	kg	4000	0.000014
Output products			
Milk	kg	279130	380 kg/d 6.33 kg/d/animal
Number of animals slaughtered	#	12	630 kg/animal
Number of calves sold	#	15	90 kg/animal
Number of suckler cows sold	#	5	400 kg/animal

Allocation

The dairy farm produces milk. It also produces animals by sending cull dairy cows and bulls to the slaughterhouse and indirectly by selling calves and suckler cows to other farms. The output products of the dairy farm are shown in Table 3.3. Allocation factors are computed by following the International Dairy Federation guidelines (IDF 2010). IDF follows a physical allocation approach by using a relationship between the energy content in the animal feed and milk and animal production. The conversion of feed to milk is more efficient use of the feed since the feed energy available for growth is lower than the feed energy available for milk production.

Table 3.3 Yearly products of the dairy farm

Product	Number of animals	Average weight	Unit sold	Total amount sold	Allocation factors IDF
		kg/unit	#/a	kg/a	%
Cull dairy cows and bulls, to slaughterhouse	82	630	12	7560	15.1
Suckler cows, sold to other farms	30	400	5	2000	4.0
Calves, sold to other farms	40	90	15	1350	2.7
Raw milk, to dairy plant and direct selling				279130	78.2

The allocation factors are used to allocate the life cycle inventory in Table 3.2 to each output product. The electricity use for the milking process as well as the refrigerant use and the milk losses are allocated 100% to the raw milk production. The refrigerant Freon emissions into air are included in the inventory. The refrigerant bought is assumed to be 100% emitted into air.

3.2.2 Slaughtering process

The life cycle inventory data of the slaughterhouse were obtained from a questionnaire filled in by a Romanian slaughterhouse named SC AGRO-INVEST PROD SRL[4] and further communication with the contact person.

Key figures

The transport distance from the dairy farm to the slaughterhouse is 46 km. The key figures of the slaughterhouse are shown in Table 3.4 in yearly amounts. The infrastructure includes the office buildings and the factory halls and a rough estimation for the machinery. The slaughtering process includes the energy, water and detergents use as well as the wastewater treatment. The data are also given per kg beef produced. The total energy use is 1.5 MJ per kg beef produced or 0.51 MJ per kg live weight.

[4] http://www.agro-invest.ro/

Table 3.4 Key figures of the slaughterhouse operation in yearly amounts 2011

		Year 2011	Per kg beef produced
Infrastructure			
Buildings office	m3	750	
Factory halls	m2	1000	
Facilities	kg	120000	
Slaughtering process			
Live weight animal	kg		3.03
Electricity	kWh	90000	0.03
Natural gas	m3 MJ	110000 4290000	1.43
Rain water	m3	4000	1.53
Tap water	m3	1000	0.33
Detergents	kg	1500	0.0005
Wastewater	m3	5000	1.91
Waste to incineration	kg		0.3

The ratios of meat to live weight animal given in the questionnaire were too high compared to literature values. Therefore, the share of bone-free meat, other edible by-products and inedible by-products are taken from FAO (2013) and are shown in Table 3.5. The bone-free meat is 33 % of the live weight cattle while 12% are other parts used in sausage. The non-edible by-products make 55 % of the live weight. All the by-products are reused except the risk materials with regard to bovine spongiform encephalopathy (BSE) that are incinerated (10 %). The incineration is modelled with the animal flour dataset shown in Table 3.6.

Table 3.5 Beef cattle products and by-products (Opio et al. 2013)

	Beef balance Romania kg/a	Share %
live weight input	3'750'000	100%
Edible		45%
Bone-free meat	1'237'500	33%
By-products for human consumption	450'000	12%
Inedible		55%
floor trimmings, blood and fats	750'000	20%
bones	300'000	8%
skins and hides	225'000	6%
digestive tract content	375'000	10%
Risk materials to incineration	375'000	10%
Lost	37'500	1%

Table 3.6 Unit process of the animal flour per kg animal carcass (Jungbluth 2000)

Animal flour processing		Per kg animal carcass
Animal flour	kg	0.37
Electricity	kWh	0.82
Light fuel oil	MJ	1.89
Tap water	kg	1.07

Allocation

The slaughterhouse processes pork and cattle. Therefore, the energy use, the water use and the detergents use must be allocated to meat and pig meat produced. The by-products are not given any economic value except the skin. The shares of each product in the turnover are given in Table 3.7. The shares of beef and pork are used as economic allocation factors.

Table 3.7 Production volumes and products' shares in turnover

Outputs	Unit	Modified amount Year 2011	Shares in turnover
Beef	kg	1323750	52.3%
Pork	kg	1668000	47.6%
Cattle skin	kg	25000	0.1%

3.2.3 Dairy plant

Life cycle inventory data of the operation of a dairy plant were obtained from a questionnaire filled in by the Romanian dairy factory Calion Prod SRL[5].

Key figures

The key figures for the dairy plant operation are shown in Table 3.8. Since no information about the facilities are provided in the questionnaire, the facilities amount of the slaughterhouse is downscaled from an ecoinvent dataset on a chemical plant (Althaus et al. 2007).

The dairy plant uses cow milk, buffalo milk and sheep milk. Since no dataset are available for the production of buffalo milk and sheep milk, the total use of raw milk has been adapted. Therefore an average fat content of 3.81% is used. The transport of the raw milk to the dairy plant is included.

Milk proteins are only used for the production of yoghurt and sour cream. Calcium chloride is only used in the cheese production. Lyophilized cultures are used in the production of yoghurt (YC-X11), soft cheese and semi-soft cheese (Flora-Danica).

Since no information about the use of refrigerants and lubricant oil nor about generated solid wastes are provided in the questionnaire, data of these inputs and outputs were taken from the environmental report of Swiss dairy plants (AZM 2001). It is assumed that all lost refrigerants are emitted into air.

With regard to product packaging, only PE milk bottles are mentioned in the questionnaire. For the other products, it is assumed that sour cream, yoghurt, curd, fresh cheese and cream cheese are packed in

[5] http://www.calion.ro

polystyrene cups. Butter is wrapped in aluminium foil. Soft cheese and semi-soft cheese are packed in plastic foil.

Table 3.8 Inputs and outputs of the operation of the dairy plant in yearly amounts 2011

Elementary and energy flows	Unit	Year 2011	Per kg of raw milk input
Area covered by factory halls	m2	566	
Area covered by (office) buildings	m3	170	
Facilities	kg	68000	
Total raw milk input	kg	590000	1
Transport of raw milk to dairy plant	tkm	12770	0.022
Electricity use	kWh	68284	0.12
Natural gas	m3	17696	0.03
Tap water	m3	716	0.0012
Calcium chloride	kg	100	0.002
Milk protein	kg	1000	0.0017
Lyophilized cultures	kg	3	0.00001
Wastewater	m3	716	0.0012
Milk losses	m3	13.6	0.00002

The turnover as well as the fat and protein content of each dairy product are shown in Table 3.9.

Table 3.9 Output dairy products at the dairy plant

Dairy product	Amount kg	Turnover %
Pasteurized milk	12600	3
Sour cream	23900	18
Yoghurt natural	11600	4
Curd	4100	1
Butter	1100	2
Fresh cheese	1400	1
Soft cheese	65000	65
Semi-soft cheese	5000	5
Cream cheese	1200	1
Whey	450000	0

Allocation IDF approach

The total raw milk input and its transport to farm, the energy and water use, materials used, wastewater and milk losses are allocated to each output dairy product using the IDF allocation matrix. The raw milk input to each dairy product and the other IDF allocation factors are show in Table 3.10. The production of 1 kg butter requires 8.4 kg raw milk. Soft cheese requires 6 kg raw milk and 1 kg cream needs 4.5 kg raw milk.

Table 3.10 Allocation of raw milk input and resources to dairy products (IDF 2010)

	Milk input	Electricity	Thermal energy	Water use	Wastewater	Milk losses	Used water in septic tanks	Milk input transport
	kg/kg	kWh/kg	MJ/kg	kg/kg	m3/kg	m3/kg	kg/kg	tkm/kg
Pasteurized milk	1.34	0.16	2.01	0.98	0.001	0.00002	0.004	0.03
Sour cream	4.49	0.16	2.01	0.98	0.001	0.00002	0.004	0.10
Yoghurt	8.42	0.40	11.4	2.63	0.003	0.00005	0.011	0.18
Curd	1.53	0.96	7.37	1.84	0.002	0.00004	0.008	0.03
Butter	1.53	0.96	7.37	1.84	0.002	0.00004	0.008	0.03
Fresh cheese	1.53	0.96	7.37	1.84	0.002	0.00004	0.008	0.03
Soft cheese	6.12	0.64	6.70	9.19	0.009	0.00018	0.039	0.13
Semi-soft cheese	1.53	0.96	7.37	1.84	0.002	0.00004	0.008	0.03
Cream cheese	6.12	0.64	6.70	9.19	0.009	0.00018	0.039	0.13
Whey	0	0	0	0	0	0	0	0

Allocation alternative scenarios

The most important parameter for the allocation in the dairy is the allocation of the raw milk input to different products. The IDF approach allocates the raw milk input based on physico-chemical parameters. There are alternatives to the IDF approach in the literature. Jungbluth (2013) allocates the raw milk input based on the fat content of the dairy products. The fat content and protein content of each dairy product given in the questionnaire is shown in Table 3.11. Sheane (2011) and Kim (2013) allocate the raw milk input based on the milk solids input and the solids content of each dairy product. The solid content refers to the dry weight of the dairy product, which is the sum of fat, protein, carbohydrate, lactose and minerals. The dry mass was not given in the questionnaire and it was estimated based on literature values (Umrechnung.org 2010). Finally, the raw milk input can also be allocated based on the turnover of each dairy product (see Table 3.9).

Table 3.11 Fat content, protein content and dry mass of the Romanian dairy inputs and products

Dairy inputs and product	Fat content %	Protein content %	Dry mass taken from literature
Raw milk	3.8	3.3	11.9
Pasteurized milk	3.5	3.3	11.5
Sour cream	20.0	2.9	22.9
Yoghurt natural	3.5	3.3	12.3
Curd	2.8	3.3	19.0
Butter	80.0	0.9	84.8
Fresh cheese	3	18	21.0
Soft cheese	23	20	54.1
Semi-soft cheese	23	25.0	59.0
Cream cheese	5	13.5	19.8
Whey	0.10	3.40	1.3

The resulting milk input for different allocation approaches is illustrated in Figure 3-2. It can be seen that there are high discrepancies between the allocation approaches especially for the butter. The raw milk input is 21 kg with the fat content approach while it is around 9 kg with the dry mass and IDF approach. The raw milk input to the pasteurised milk is lower with the fat content approach (0.92 kg) while it is between 1.2 kg and 1.4 kg with the other approaches. This difference is also found for the yoghurt, the curd, the fresh cheese and the cream cheese. The dry mass allocation and the IDF allocation have similar raw milk input for the pasteurised milk, the butter, the yoghurt, the soft cheese and semi-soft cheese. The difference is wider for the cream, the curd, the fresh cheese and the cream cheese. The difference is explained by the dry mass values which were taken from literature. The difference would be smaller if the fat content would also be taken from the same literature source. With the economic procedure, whey does not bear any environmental impacts because it is given free to be processed into animal feed. The fat content of whey is 0.1 % so its raw milk input is not visible in the figure. With the dry mass allocation, the raw milk input to whey is just 0.14 kg. No allocation factor was available for the whey with the IDF allocation, the allocation factors are only provided for the whey powder. The difference between the economic allocation and the other allocation for the fresh cheese and cream cheese could be explained by a rounding error in the turnover shares given in the questionnaire.

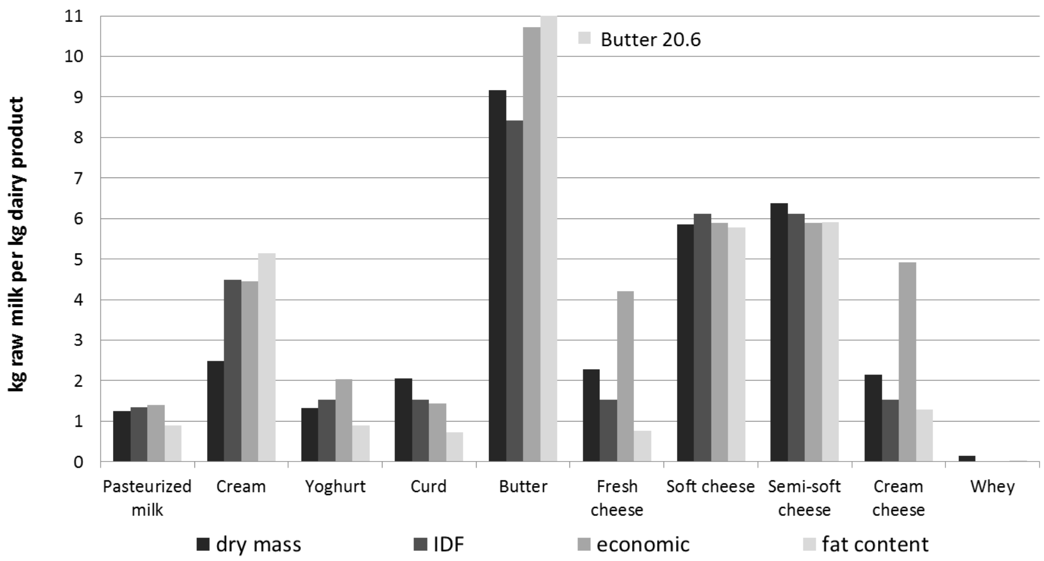

Figure 3-2 Comparison of the raw milk input depending on the allocation approach

An "alternative" allocation scenario is assessed in this study in order to investigate the relevance of this issue for the single dairy products. In this scenario the raw milk input is allocated based on the fat content. The other resources consumed at the dairy plant (electricity, natural gas, steam, detergents etc.) are allocated based on the shares of the dairy product in turnover. The resulting allocation is shown in Table 3.12.

Table 3.12 Allocation of raw milk input and resources to dairy products with the alternative allocation approach

	Milk input	Electricity	Thermal energy	Water use	Wastewater	Milk losses	Used water in septic tanks	Milk input transport
	kg/kg	kWh/kg	MJ/kg	kg/kg	m3/kg	m3/kg	kg/kg	tkm/kg
Pasteurized milk	0.90	0.16	1.64	1.70	0.0017	0.00002	0.0071	0.1014
Sour cream	5.14	0.51	5.20	5.39	0.0054	0.00012	0.0226	0.1014
Yoghurt	0.90	0.24	2.38	2.47	0.0025	0.00002	0.0103	0.1014
Curd	0.72	0.17	1.68	1.75	0.0017	0.00002	0.0073	0.1014
Butter	20.57	1.24	12.55	13.02	0.0130	0.00048	0.0545	0.1014
Fresh cheese	0.77	0.49	4.93	5.11	0.0051	0.00002	0.0214	0.1014
Soft cheese	5.78	0.68	6.90	7.16	0.0072	0.00013	0.0300	0.1014
Semi-soft cheese	5.91	0.68	6.90	7.16	0.0072	0.00014	0.0300	0.1014
Cream cheese	1.29	0.57	5.75	5.97	0.0060	0.00003	0.0250	0.1014
Whey	0.03	0	0	0	0	0	0	0

3.3 Life Cycle Impact Assessment

All impact categories according to Table 2.1 are shown in the graphics and tables. They are assessed one by one.

3.3.1 Beef

Cull dairy cow and bulls at dairy farm

The environmental impacts of 1 kg cull dairy cow at dairy farm are illustrated in Figure 3-3. The impact assessment shows that the resource use and emissions related to the crop cultivation for the fodder production represent the most significant relative impacts across multiple environmental midpoint indicators. Indeed, the application of manure and fertilisers, the diesel use and agricultural machinery manufacture and use as well as the land and water used are the main contributors to all the impact categories. The results for each impact category are given in Table 3.14.

The global warming potential of 1 kg cull dairy cow at dairy farm is 10.7 kg CO_2-eq. It is the only impact category where the animal husbandry has a higher contribution than the fodder production. Indeed, the direct cattle emissions, i.e. the methane emissions from the enteric fermentation, contribute 70 % to the climate change effect (6.9 kg CO_2-eq). The emissions from the agricultural machinery manufacture and use cause 20 % of the climate change impacts.

The P_2O_5-fertilisers generate 50 % of the human toxicity cancer effects and 35 % of the human toxicity non-cancer effects. This contribution is caused by the emissions of chromium, zinc and copper after application on the field, which depend on their content in the fertiliser. The figures used are related to the fertiliser production in the background system.

The agricultural machinery causes 30 % and 60 % of the human toxicity cancer effects and non-cancer effects, respectively. The contribution of the agricultural machinery is explained by the zinc emissions from the tyre abrasion and the chromium emissions resulting from the machinery manufacture. Both are background data. The main difference between the cancer effects and the non-cancer effects is the chromium which does not have any human toxicity non-cancer effects.

The NH_3 and NO_X emissions due to the spreading of manure causes around 55 % of the impacts. The NH_3 emitted by the cattle in stall contribute 20 % to the impacts. The NO_x emissions due to the diesel use and the SO_2 emissions due to the manufacture of the agricultural machinery contribute 10 % to the results.

The freshwater eutrophication is due mainly to the phosphate and phosphorus leaching due to the land use (75 %).

The NO_3 emissions due to the spreading of manure dominate the marine eutrophication (60 %). The NO_3 emissions resulting from the use of N-fertiliser contribute 20 % to the effects. The diesel combustion related to the agricultural machinery emits NO_X emissions which generate 15 % of the impacts.

The use of herbicides contributes 11 % to the freshwater ecotoxicity impacts due to the emissions of the active ingredient. The application of P_2O_5-fertilisers, the diesel combustion and the manufacture of the agricultural machineries cause 30 % and 40 % of the ecotoxicity impacts, respectively. The reasons are the same as the ones described for the human toxicity impact category. Indeed, the heavy metals such as chromium and zinc have high characterisation factors in the USEtox impact assessment method.

Land use is obviously dominated by the land occupation at the farm (90 %).

Water depletion is also dominated by the water consumption at the farm (60 %). The manufacture of the agricultural machineries causes 20 % of the water depletion. The P_2O_5-fertilisers production and the construction of buildings each contribute around 10 % to the water depletion impacts.

The crude oil extraction required for the diesel production is responsible for 80 % of the abiotic resource depletion impacts. The buildings materials account for 8 % of the results.

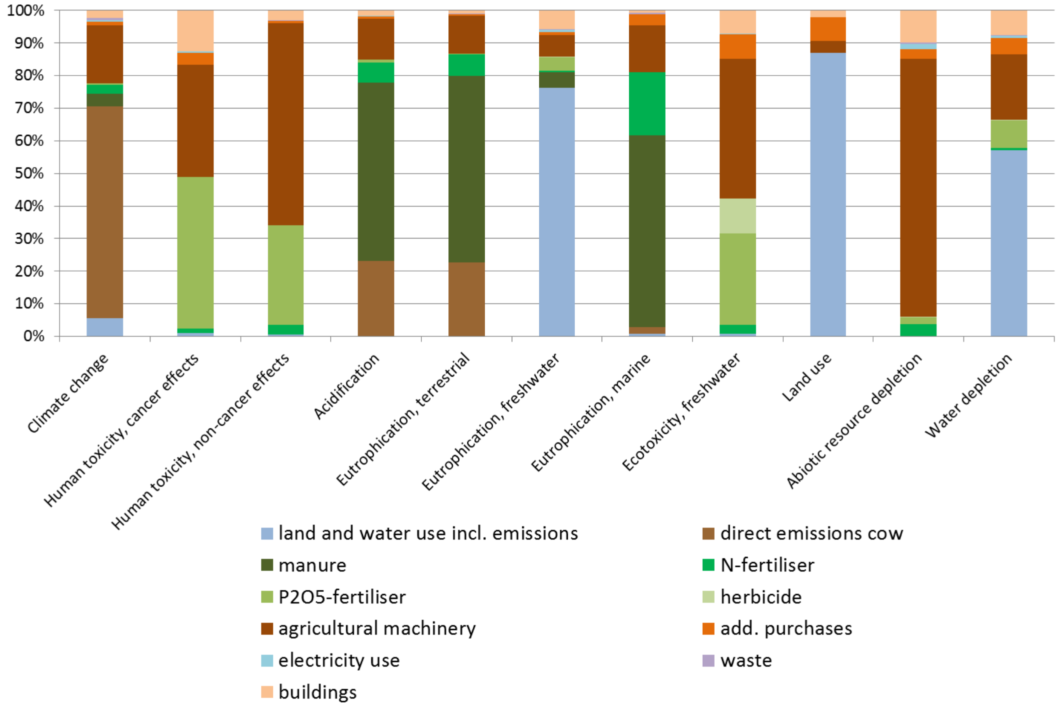

Figure 3-3 Comparison of the environmental impacts of cull dairy cow and bull at dairy farm. The results are shown on a relative scale (100%) for different parts of the farm operation.

Table 3.13 Legend explanation

Legend	Included processes
Land and water use, incl. emissions	Land occupied for the crop cultivation, grazing and fallow land as well as the phosphorus emissions to water and N_2O emissions to air from the cultivated soil not directly dependent on fertilizer use. The water use and the wastewater treatment are also included
Direct emissions cattle (not only dairy cows)	Enteric fermentation CH_4 emissions and NH_3 emissions due to animal excrement in stall
Manure	Emissions to air (N_2O, NH_3, NO_x) and water (PO_4, NO_3) caused by the application of manure on the fields
N-Fertiliser	Chemical production, transport and emissions to air (N_2O, NH_3, $NO_{x)}$, water (NO_3) and soil (element content) due to the use
P2O5-Fertiliser	Chemical production, transport and emissions to water (PO_4) and soil (element content) due to the use
Herbicide	Chemical production, transport and emissions to soil (element content) due to the use
Agricultural machinery	Manufacture of agricultural machineries (tractor, trailer, harvester, tillage…) and shed for storage. Diesel consumption including emissions resulting from the diesel combustion and emissions to soil from the tyre abrasion
Additional purchases	Seeds, cattle salt and mineral feed, liquid nitrogen
Electricity use	Electricity consumption for the pumps and mills
Waste	Waste disposal (packaging, syringes, dead animals)
Buildings	Office, storehouse and cattle housing

Beef at slaughterhouse

In the second assessment the impacts of the slaughtering and packaging processes are included. The main life cycle step is the dairy farm as illustrated in Figure 3-4. The slaughtering and packaging contribute less than 10% to the total results with the exception of the abiotic resource depletion impact category. This is due to the electricity use at the slaughterhouse as well as the electricity use for the slaughtering waste incineration. The contribution of the packaging, which consists of a vacuum plastic, is negligible to all impact categories.

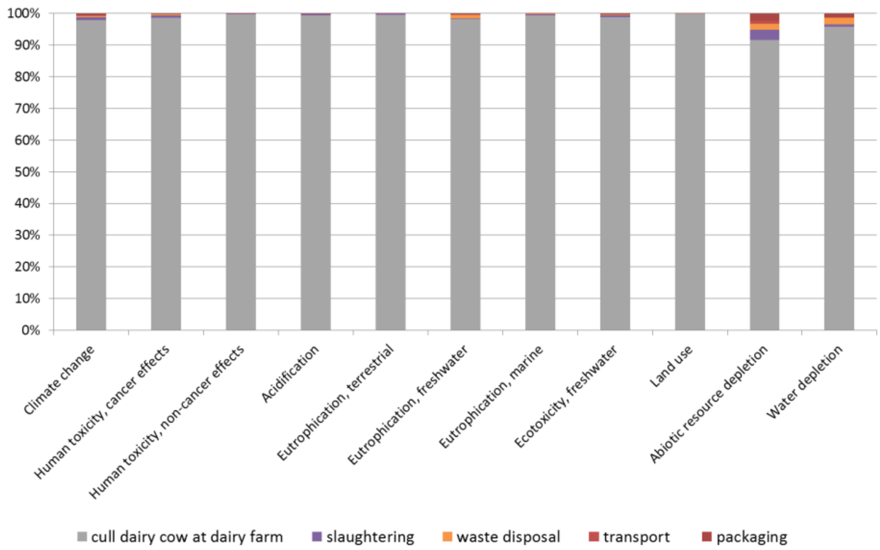

Figure 3-4 Life cycle impact assessment of the beef at the slaughterhouse and comparison among several impact categories. Impacts are shown on a relative scale (100%).

Legend	Included processes
Cull dairy cow at dairy farm	Animal husbandry at dairy farm including feed production
Transport	Transport of cull dairy cow from dairy farm to slaughterhouse
Slaughtering	Energy use, water use, cleaning product, infrastructure
Waste disposal	Transformation of animal waste into animal flour (electricity use, thermal energy, tap water) and incineration
Packaging	Plastic vacuum packaging

The overall results are shown in Table 3.14. The global warming potential of 1 kg of Romanian beef at slaughterhouse is 33 kg CO_2-eq.

Table 3.14 LCIA results per kg beef at the slaughterhouse

Impact category	Unit	Total	Farm	Share farm	Slaughtering	Packaging
Climate change	kg CO2 eq	3.30E+01	3.24E+01	98%	4.65E-01	1.80E-01
Human toxicity, cancer effects	CTUh	4.59E-07	4.52E-07	99%	5.57E-09	1.01E-09
Human toxicity, non-cancer effects	CTUh	1.41E-05	1.41E-05	100%	2.50E-08	6.01E-09
Acidification	molc H+ eq	4.05E-01	4.03E-01	99%	1.78E-03	7.36E-04
Eutrophication, terrestrial	molc N eq	1.84E+00	1.83E+00	100%	5.58E-03	1.33E-03
Eutrophication, freshwater	kg P eq	3.10E-03	3.04E-03	98%	4.51E-05	1.13E-05
Eutrophication, marine	kg N eq	1.35E-01	1.35E-01	99%	7.28E-04	1.21E-04
Ecotoxicity, freshwater	CTUe	1.47E+01	1.46E+01	99%	1.40E-01	2.35E-02
Land use	kg C deficit	8.59E+02	8.58E+02	100%	4.47E-01	6.65E-02
Abiotic resource depletion	kg Sb eq	5.55E-02	5.09E-02	92%	3.36E-03	1.28E-03
Water depletion	m3 water eq	1.91E-02	1.82E-02	96%	5.84E-04	2.28E-04

The contribution of each life cycle stage to the environmental impacts does not allow identifying where the main impacts occur within each category. It is difficult to identify from Figure 3-4 if the impacts are due to emissions occurring in the foreground system, e.g. at the dairy farm, or in the background system. Therefore, the main substances contributing to the environmental impacts of the acidification, terrestrial and freshwater eutrophication and climate change impact categories are identified together with their sources.

The acidification and terrestrial eutrophication are due mainly to ammonia and nitrogen oxides emissions occurring at the dairy farm. The ammonia emissions result from the animal husbandry and the manure application on fields. The nitrogen oxides emissions are due to the diesel combustion and the manure application on fields. The use of N-fertiliser contributes to a minor extent to the nitrogen oxides and ammonia emissions.

The main substances contributing to the freshwater eutrophication are phosphate emissions caused by the leaching of phosphate and the erosion of phosphorus from the cultivated land. Phosphate emissions caused by the application of manure are also a small contributor to the impacts.

The main substances contributing to the climate change are methane, carbon dioxide and dinitrogen monoxide. The methane emitted through the cattle enteric fermentation is the main contributor followed by the carbon dioxide emitted during the diesel combustion. The land use and the N2O emissions from crop residues, the application of manure and the use of N-fertiliser emit dinitrogen monoxide in the foreground system. Background emissions include carbon dioxide emitted during the agricultural machinery manufacture.

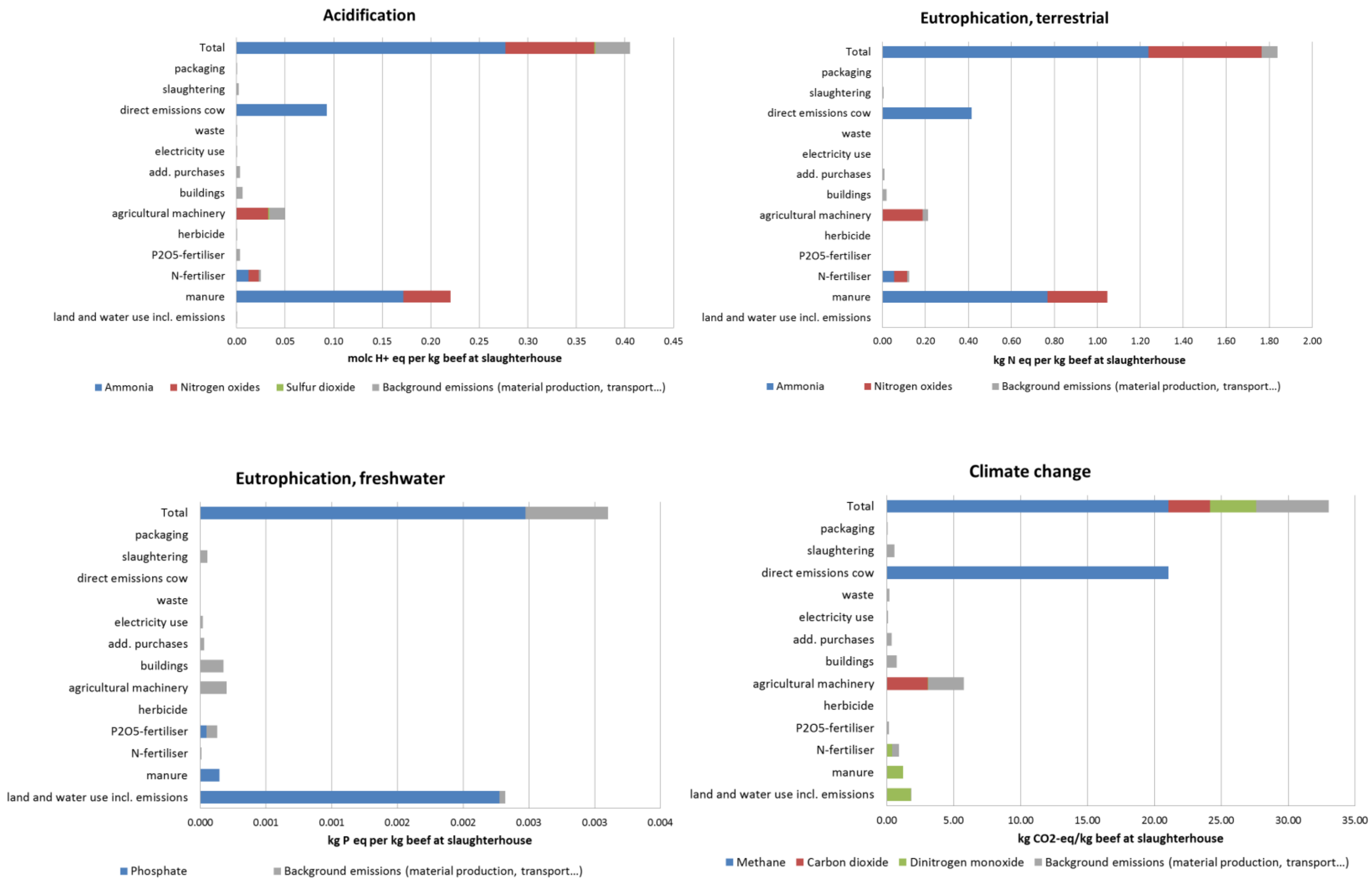

Figure 3-5 Acidification, terrestrial and freshwater eutrophication and climate change LCIA per life cycle steps. Share of direct emission at process stage and background emissions

The Figure 3-6 shows the main primary resources contributing to the abiotic resource depletion of beef. It can be seen that the diesel production used by the agricultural machineries is the main contributor to the crude oil consumption while the agricultural machinery manufacture is the main contributor to the hard coal consumption and a contributor to the crude oil consumption. Small contributors are the construction of buildings and the slaughtering process.

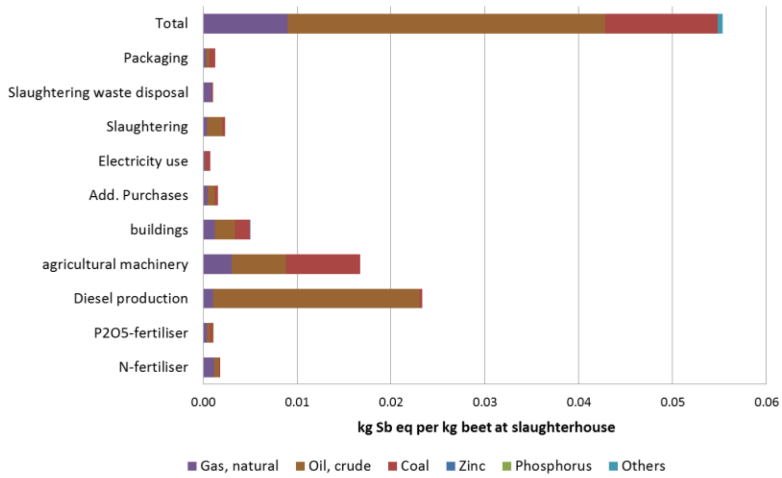

Figure 3-6 Main substances contributing to the abiotic resource depletion

3.3.2 Dairy products

Raw milk at dairy farm

The impact assessment of the raw milk input to the dairy products is shown in Figure 3-7. The legends are the same as those used for the beef impact assessment in Table 3.13 with the exception of the additional label milking, which corresponds to the milking process and includes the milking parlour, energy and water use, refrigerant and other cleaning products use as well as refrigerant emissions.

The GWP of 1 kg raw milk at the dairy farm is 1.1 kg CO2-eq. The only difference with the assessment of the cull dairy cow is the milking process, which contributes 15% to the abiotic resource depletion and 5% to the human toxicity cancer effects due to the electricity use and the construction of the milking parlour. The water use during the milking process causes 20% of the water depletion effects. The electricity use contributes also 6% to the freshwater eutrophication.

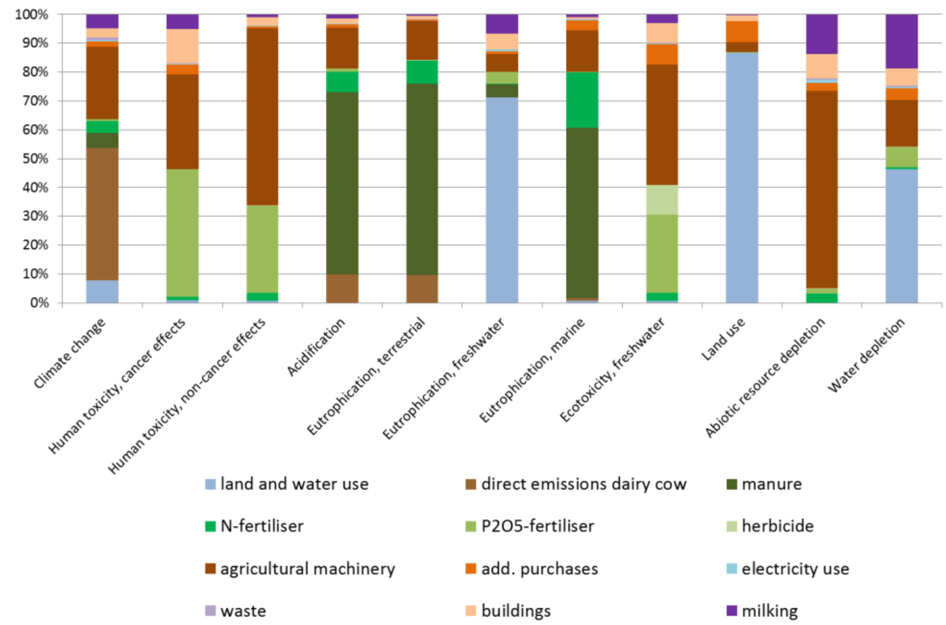

Figure 3-7 LCIA results of raw milk at dairy farm. The results are shown on a relative scale (100%).

Dairy products at dairy plant

In Figure 3-8 the global warming potentials of the dairy products are shown, calculated with two allocation approaches. The chart is differentiated for the contribution of raw milk and the processing. On the left side, results with the IDF allocation can be found. Since the allocation factors are the same for soft cheese and semi-soft cheese, the GWP and other results are the same. The allocation factors for cream cheese, curd, fresh cheese and yoghurt are the same. Therefore the raw milk contribution to the GWP of these dairy products is the same. Since no difference in the inventory is made between cream cheese and fresh cheese, the GWP end results are the same. However, the GWP end result is different for yoghurt because milk protein and lyophilized cultures are added to the yoghurt production. The curd has a slightly lower environmental impact due to the use of calcium chloride in both cream cheese and fresh cheese. The butter has the highest GWP followed by the soft cheese and the sour cream. The raw milk contributes at least 70 % to the global warming potential of the pasteurized milk, butter, soft cheese and sour cream. It contributes only 50 % to the global warming potential of yoghurt, fresh cheese, cream cheese and curd due to the higher allocation of electricity and fuel to these dairy products. However, the raw milk input is different for each dairy product. The production of 1 kg butter requires 8.4 kg raw milk and its GWP is 10.5 kg CO2-eq. The production of 1 kg pasteurized milk needs 1.3 kg raw milk and its GWP is 1.93 kg CO2-eq.

On the left side of Figure 3-8 results for the alternative allocation approach are shown. It can be seen that with the IDF approach the differences between different products are less pronounced than with alternative approach. The GWP of the other dairy products are lower in the alternative allocation approach with the exception of the butter and the sour cream. The raw milk input of the butter is much higher with the allocation by fat content (21 kg) than with the IDF allocation approach (8.4 kg). Therefore, the GWP of the butter is 22 kg CO_2 - eq with the alternative allocation and 10.5 kg CO_2 - eq with the IDF allocation, respectively. The raw milk input of the pasteurised milk is 0.9 kg with the fat content allocation while it is 1.3 kg with the IDF allocation. Therefore the GWP of the pasteurised milk is 1.4 kg CO_2 – eq with the alternative allocation and 1.9 kg CO_2 – eq with the IDF allocation. Considering the yoghurt, its raw milk input is 0.9 kg and its GWP is 1.8 kg CO_2 – eq with the alternative allocation. With the IDF allocation, its raw milk input is 1.5 kg and its GWP is 3.3 kg CO_2 – eq.

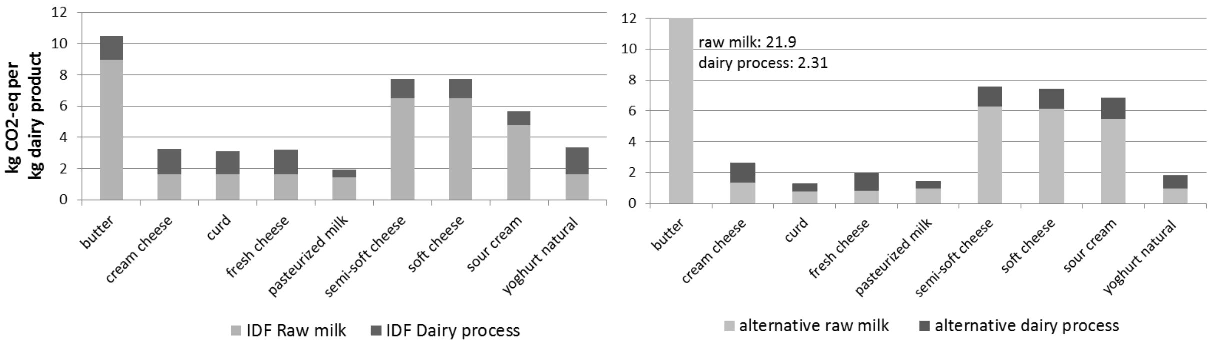

Figure 3-8 Comparison of the GWP of the dairy products at the dairy plant with the IDF allocation (left side) and the alternative allocation approach (right side)

The abiotic resource depletion potential of all dairy products is shown in Figure 3-9. The abiotic resource depletion is the highest for the butter followed by the soft cheese and the sour cream. The contribution of the raw milk impacts is smaller due to the energy use at the dairy plant. More resources are depleted from the energy consumption than from the milk production at farm.

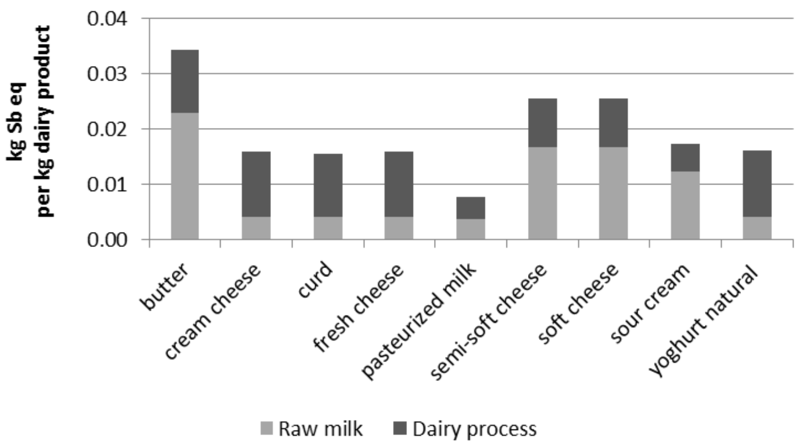

Figure 3-9 Abiotic resource depletion of the dairy products at the dairy plant

In the following discussion, the semi-soft cheese is omitted since its environmental impact is similar to the soft cheese. The same applies to the cream cheese, which is identical to the fresh cheese. The environmental impacts of pasteurized milk, butter, soft cheese, sour cream, yoghurt, curd and fresh cheese are shown one by one below. Table 3.15 summarizes the LCIA results.

Pasteurised milk

In Figure 3-10, the LCIA of the pasteurized milk is shown. The figure focuses on the dairy plant contribution. The grey bar represents the raw milk input, which was discussed before. The raw milk input contributes almost 80% to the impacts with the exception of the climate change, abiotic resource depletion and water depletion impact categories. 75 % of the climate change and 45 % of the abiotic resource depletion are due to the dairy farm. The energy use at the dairy plant and the PE-bottle packaging contribute 25% and 20% to the abiotic resource depletion, respectively. They cause 10% and 20% of the climate change impacts, respectively. The main contributors are the PE material and the energy use during the blow moulding process.

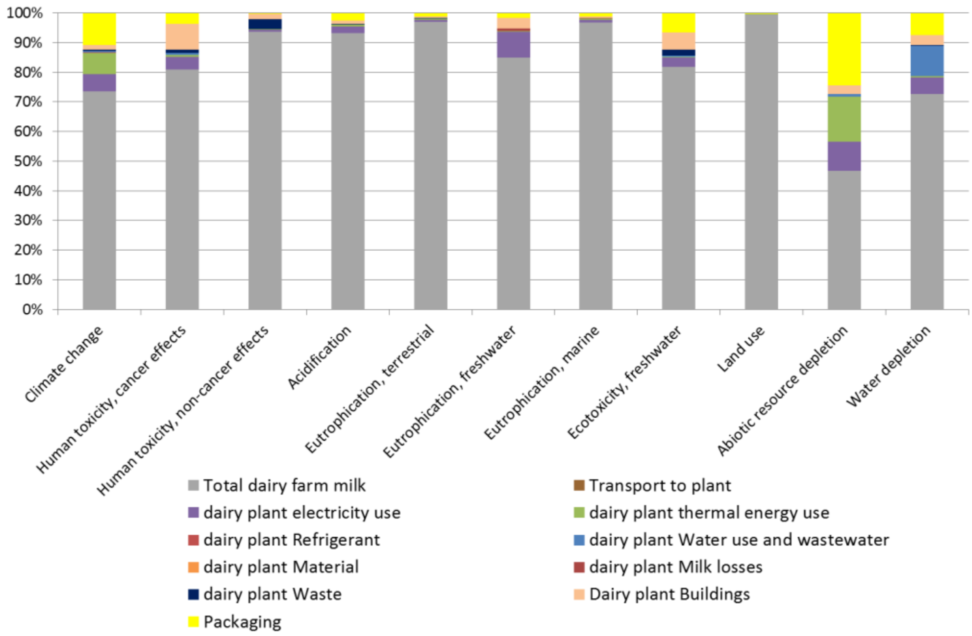

Figure 3-10 Contribution analysis of LCIA for pasteurized milk

Butter

The LCIA results for 1 kg of butter are illustrated in Figure 3-11. The raw milk input, represented with a grey bar, contribute 80% to all impact categories except for the abiotic resource depletion. The thermal energy use causes 25% of the abiotic resource depletion effects. This is due to the high allocation factor for thermal energy to the butter. The dairy plant buildings contribute 10% to the human toxicity cancer effects due to the facilities included in the dataset, which require chromium steel. The same explanation is valid for the ecotoxicity impact category.

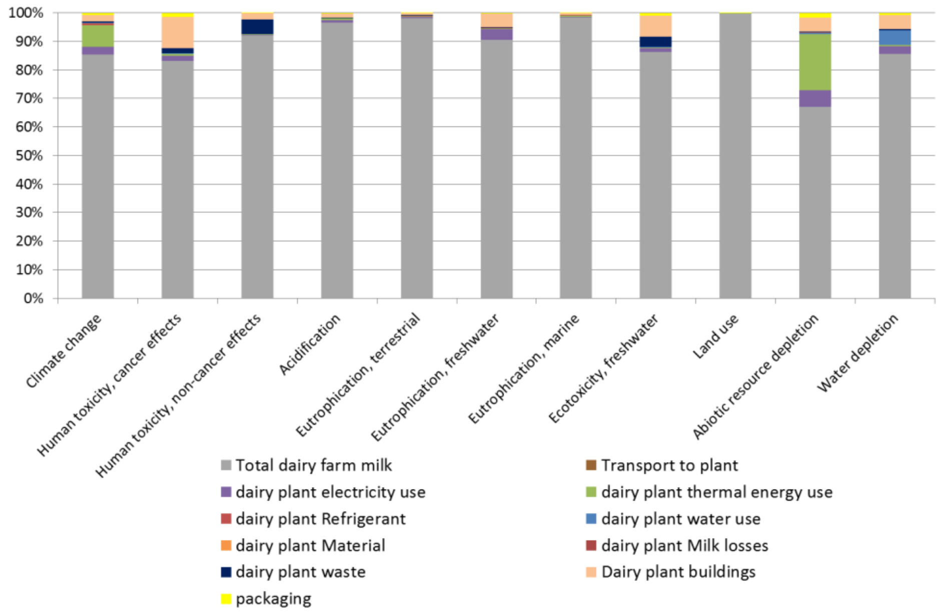

Figure 3-11 Contribution analysis of LCIA for butter

Soft cheese

The LCIA of soft cheese is shown in Figure 3-12. The raw milk input contributes at least 80% to all impact categories except for the abiotic resource depletion. In comparison with the butter, the contribution of electricity is higher while the contribution of thermal energy is smaller due to a higher allocation factor to electricity use and a smaller allocation factor to thermal energy. The main difference is the tap water contribution to the water depletion effects due to the higher allocation factor for the water use to the soft cheese production.

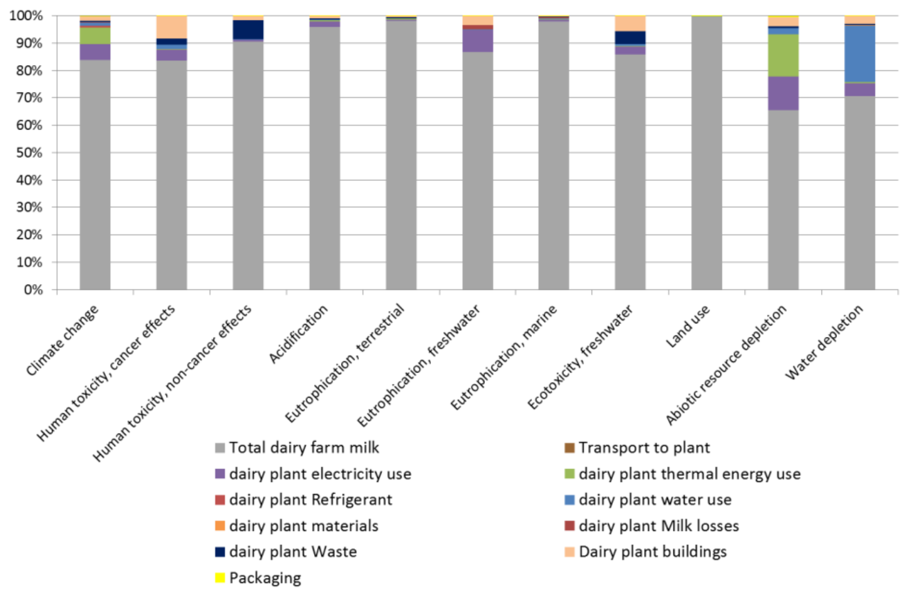

Figure 3-12 Contribution analysis of LCIA results for soft cheese

Sour cream

The environmental impacts of the sour cream are dominated by the raw milk input as shown in Figure 3-13. 4.5 kg of raw milk are needed to produce 1 kg of sour cream. The addition of milk protein during the sour cream processing increases also the contribution of milk to the sour cream processing.

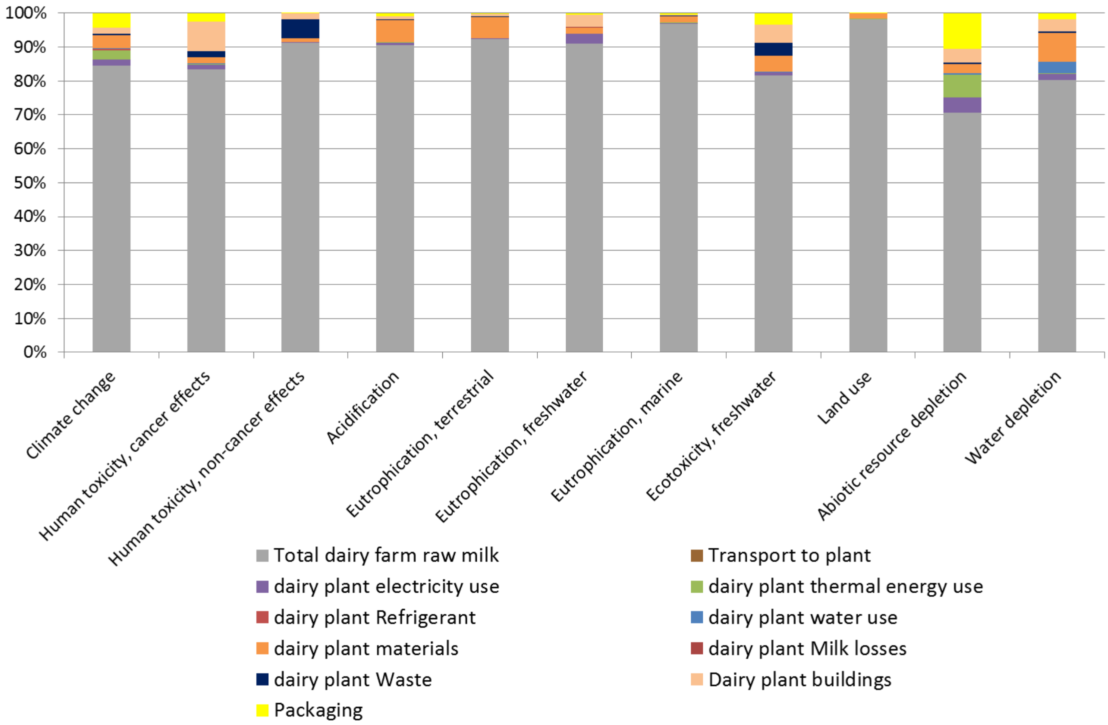

Figure 3-13 Comparison of the environmental impacts of sour cream at the dairy plant. Results are shown on a relative scale (100%)

Yoghurt

The LCIA results for the yoghurt are displayed in Figure 3-14. The results are different than those for pasteurized milk, butter and soft cheese since the raw milk input contributes only 60% to the results. The energy use has a higher contribution to the results due to the higher allocation factor for the electricity use to the yoghurt production. The energy use causes 35% of the climate change impacts, 30% of the freshwater eutrophication and 50% of the abiotic resource depletion effects. The main reason is that around 40% of the Romanian electricity mix relies on fossil fuels, more specifically lignite (Itten et al. 2012). Using lignite as a fossil fuel contributes to the depletion of abiotic resources. Moreover, lignite burned in power plant emits carbon dioxide. The disposal of lignite ashes resulting from the lignite burned in power plant emits phosphate and contributes to the freshwater eutrophication and human toxicity cancer effects.

Milk proteins, used in the yoghurt production, are modelled with a dataset on milk powder, which needs raw milk as an input. Therefore, the use of milk proteins (labelled with the legend “dairy plant materials”) causes almost 15% of the acidification, terrestrial eutrophication, ecotoxicity and water depletion. The yoghurt packaging is modelled with a polystyrene cup with an aluminium lid. The manufacture of polystyrene explains its contribution to the abiotic resource depletion, freshwater ecotoxicity and climate change impact categories.

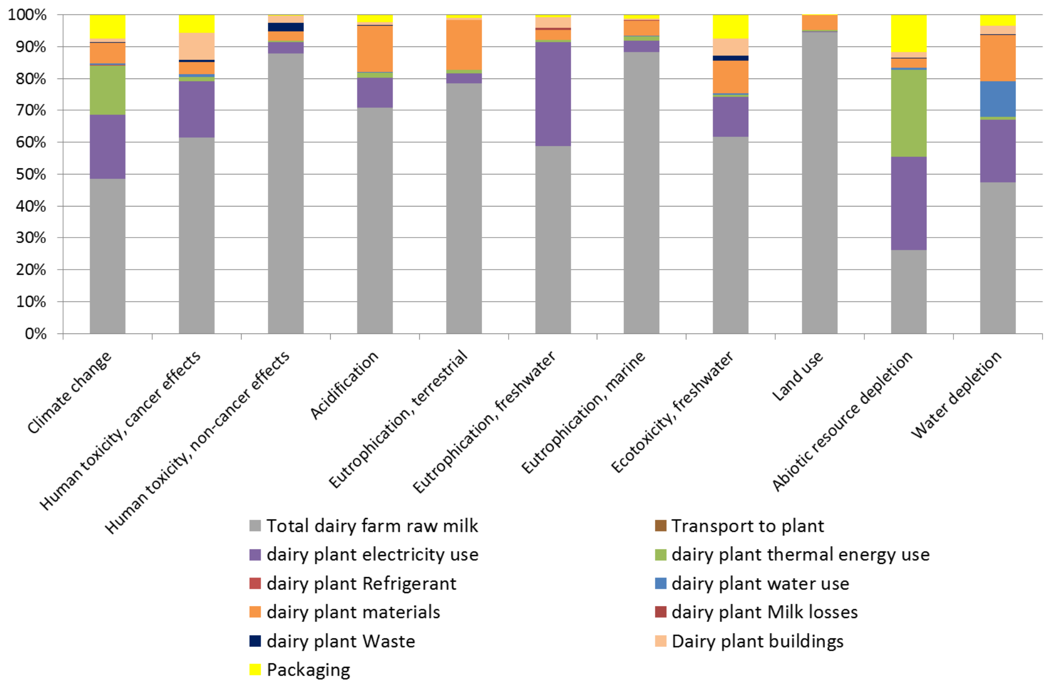

Figure 3-14 Contribution analysis of LCIA for yoghurt

In Figure 3-15the abiotic resource depletion is illustrated per life cycle stages. The main contributors are the electricity and natural gas use at the dairy plant as well as the diesel production required for the diesel use by tractors at the dairy farm. The packaging material requires polystyrene.

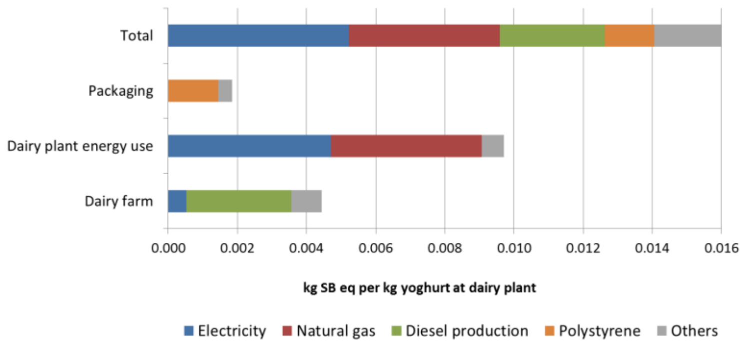

Figure 3-15 Main steps contributing to the abiotic resource depletion of the yoghurt at dairy plant

Curd

The environmental impacts of the curd are depicted in Figure 3-16. The results are very similar to those of the yoghurt since the allocation factors are the same. The only difference is the absence of milk protein addition during the processing, which is labelled under “dairy farm materials” in Figure 3-14 for the yoghurt environmental impacts.

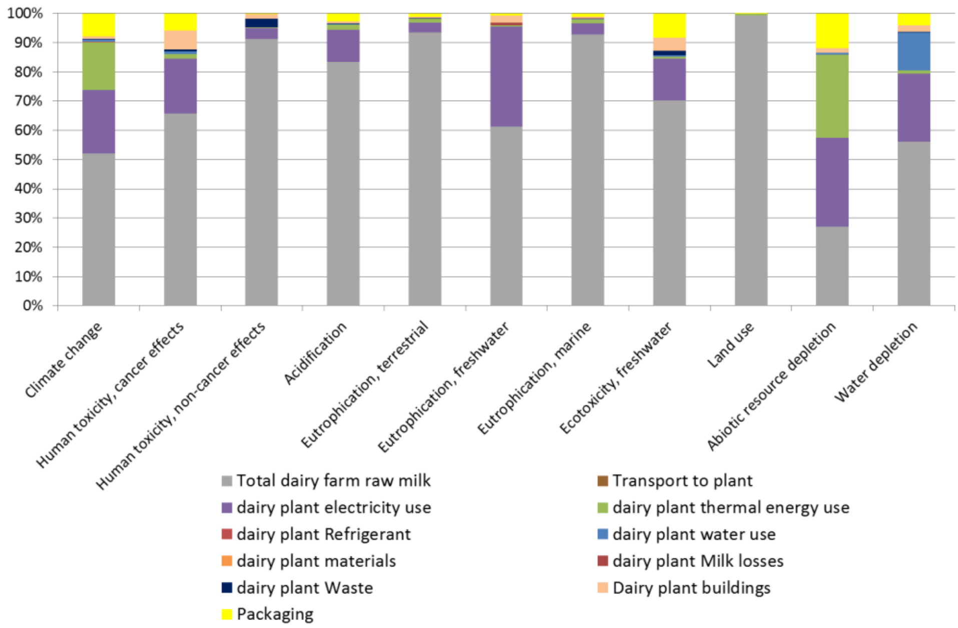

Figure 3-16 Comparison of the environmental impacts of curd at dairy plant. Results are shown on a relative scale

Fresh cheese

The environmental impacts of fresh cheese are similar to yoghurt and curd since the allocation factors are the same (see Figure 3-17). The contribution of the buildings is higher due to the higher allocation factor.

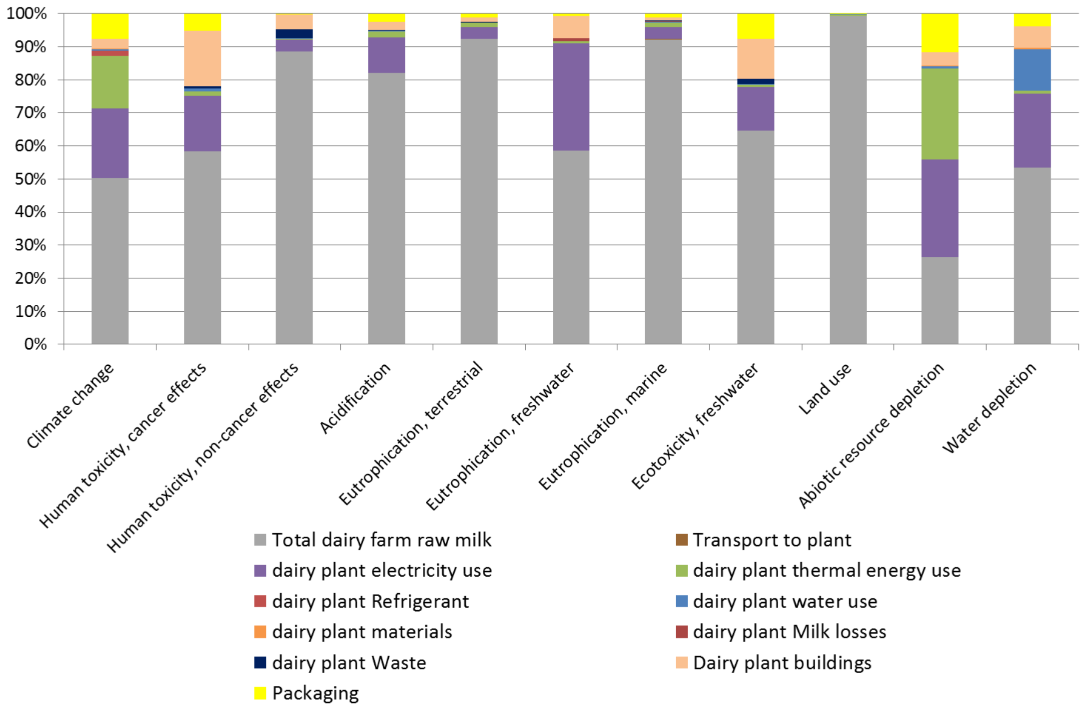

Figure 3-17 Comparison of the environmental impacts of fresh cheese at dairy plant. Results are shown on a relative scale (100%)

Table 3.15 LCIA results per kg dairy product

Impact category	Unit	Raw milk	Pasteurised milk		Butter		Soft cheese		Sour cream		fresh cheese		Yoghurt		Curd	
		Total	Total	Raw milk	Total	Raw milk	Total	Raw milk	Total	Raw milk	Total	raw milk	Total	Raw milk	Total	Raw milk
Climate change	kg CO2 eq	1.06E+00	1.93E+00	74%	1.05E+01	90%	7.76E+00	84%	5.66E+00	84%	3.24E+00	50%	3.35E+00	48%	3.13E+00	52%
Human toxicity, cancer effects	CTUh	2.21E-08	3.65E-08	81%	2.23E-07	83%	1.62E-07	84%	1.19E-07	83%	5.78E-08	58%	5.49E-08	62%	5.14E-08	66%
Human toxicity, non-cancer effects	CTUh	6.59E-07	9.42E-07	94%	6.02E-06	92%	4.45E-06	91%	3.25E-06	91%	1.14E-06	88%	1.15E-06	88%	1.11E-06	91%
Acidification	molc H+ eq	1.62E-02	2.32E-02	93%	1.41E-01	97%	1.03E-01	96%	8.02E-02	91%	3.02E-02	82%	3.49E-02	71%	2.97E-02	83%
Eutrophication, terrestrial	molc N eq	7.31E-02	1.01E-01	97%	6.26E-01	98%	4.56E-01	98%	3.56E-01	92%	1.21E-01	92%	1.42E-01	79%	1.20E-01	93%
Eutrophication, freshwater	kg P eq	1.51E-04	2.38E-04	85%	1.40E-03	91%	1.06E-03	87%	7.45E-04	91%	3.94E-04	59%	3.92E-04	59%	3.76E-04	61%
Eutrophication, marine	kg N eq	6.20E-03	8.57E-03	97%	5.31E-02	98%	3.88E-02	98%	2.88E-02	97%	1.03E-02	92%	1.07E-02	88%	1.02E-02	93%
Ecotoxicity, freshwater	CTUe	6.96E-01	1.14E+00	82%	6.79E+00	86%	4.96E+00	86%	3.84E+00	82%	1.65E+00	65%	1.73E+00	62%	1.52E+00	70%
Land use	kg C deficit	3.98E+01	5.35E+01	100%	3.36E+02	100%	2.44E+02	100%	1.82E+02	98%	6.14E+01	99%	6.44E+01	95%	6.14E+01	99%
Abiotic resource depletion	kg Sb eq	2.73E-03	7.81E-03	47%	3.42E-02	67%	2.55E-02	65%	1.74E-02	71%	1.59E-02	26%	1.60E-02	26%	1.54E-02	27%
Water depletion	m3 water eq	1.20E-03	2.21E-03	73%	1.18E-02	86%	1.04E-02	71%	6.70E-03	80%	3.43E-03	53%	3.86E-03	47%	3.27E-03	56%

3.4 Discussion

The impact assessment results presented in the previous section 3.3 are interpreted. The most relevant stages are identified and the allocation rules are discussed for the beef and dairy products. The identification of the impact drivers allows the selection of the KEPIs. Finally, the regionalisation potential is discussed.

3.4.1 Beef

Most relevant stages

The relevant environmental impacts are the resource depletion and the emissions related to the crop cultivation for the fodder production at the farm. The land cultivation, the production and application of fertilisers, the application of manure and liquid manure as well as the manufacture and use of agricultural machineries are the most relevant stages. The methane emissions resulting from the enteric fermentation of the cattle is the main contributor to the GWP. The P_2O_5 production is modelled according to different types of fertilisers use in Switzerland. This influences the content of elements and their respective emissions to soil, e.g. chromium, zinc etc. These emissions are relevant for the impact categories human toxicity and freshwater toxicity that are based on the USEtox impact assessment method. The diesel use is modelled together with the agricultural machineries, e.g. tractor, trailer, harvester etc. The manufacture of the agricultural machineries emits chromium and zinc due to the tyre abrasion. These emissions from the background system are relevant for the USEtox method applied in this case study (see Table 3.16).

The less relevant flows at the dairy farm are the herbicides, additional purchases of some materials, the electricity use and the buildings. The herbicides are only relevant for the freshwater ecotoxicity. The additional purchases (seeds purchased, cattle salt, mineral feed, liquid nitrogen) are not relevant to the impacts. Moreover, the electricity consumption for the pumps and mills is also not significant for the impacts. The wastes are also not an important issue. The slaughtering and packaging stages are negligible in this case study.

Table 3.16 Most relevant life cycle stages for the life cycle assessment of the beef at slaughterhouse

Impact category	Impact drivers	Key substances
Climate change	Enteric fermentation, agricultural machinery manufacture and use, slaughtering waste processing	methane, carbon dioxide
Human toxicity, cancer effects	P2O5-fertilizer use, agricultural machinery manufacture, buildings	chromium
Human toxicity, non-cancer effects	P2O5-fertilizer use, agricultural machinery use	zinc
Acidification	Manure application, cattle emission in open yard, agricultural machinery use, N-fertilizer	ammonia, nitrogen oxides
Eutrophication, terrestrial	Manure application, cattle emission in open yard, agricultural machinery use, N-fertilizer	ammonia, nitrogen oxides
Eutrophication, freshwater	Phosphate runoff and leaching from cultivated land	phosphate
Eutrophication, marine	Manure application, N-fertilizer and agricultural machinery use	nitrate, nitrogen oxides
Ecotoxicity, freshwater	P2O5-fertilizer use, herbicide use, agricultural machinery production and use, buildings	chromium, zinc
Land use	Cultivated area	land
Abiotic resource depletion	Agricultural machinery manufacture, fuel production	Crude oil, coal, natural gas
Water depletion	Water use at farm, agricultural machinery fuel production, P2O5-fertilizer production	water

The Romanian dairy farm assessed in the inventory might not represent a European average. Fodder and crops required to produce the animal feed is cultivated on the farm. Animals are fed with high quality forage, which do not contain any purchased grains. However, most farms in Europe purchase animal feed. In these cases, environmental impacts are dominated by the animal feed production, which might be quite variable due to the variety in the basic ingredients used: soy beans, maize, by-products of food and bioenergy production etc.

Allocation rules

At the slaughterhouse, an allocation between the pig and cattle slaughtered is made by using the shares in turnover of pork and beef. However, no allocation is applied between the production of beef and the beef cattle co-products such as skin, bones, fat etc. In the annex D of the Envifood protocol, it is written that the partners have not reached an agreement on the allocation for co-products of the meat chain. (ENVIFOOD 2012). During the SENSE WP1 Meeting, one participant informed that a mass allocation is under discussion. In the report published by the FAO on the global life cycle assessment of ruminants, no allocation is performed for the slaughter by-products due to the lack of comprehensive global data (Opio et al. 2013). An economic allocation is discussed in the report, which would lead to an allocation value of 6 % to the by-products. Similarly, Cederberg (2009) mentions that "none of the calculated GHG emissions were allocated to the meat production by-products". Consequently, it is suggested that all the emissions are allocated to the meat production in the SENSE tool.

In the Envifood protocol, the economic allocation should be done by commissioning "an independent research group to collect actual prices of fractions averaged over three years and only publish the ratio of weighted average prices" (ENVIFOOD 2012). Due to restrictions in time and budget of this project such an approach was not possible. It also seems to be difficult to apply it for the SENSE tool. It is considered to be more consistent to have all inventory data related to a fixed period e.g. one year. One solution would be to have all inventory data over a three-year average but this goes beyond the scope of this project.

Comparison with literature values

The GWP of the Romanian beef is in the range of the other literature values identified in Landquist (2013). In this case study, beef is produced by culled dairy cows that also produced milk during their life. Therefore, an allocation is made between beef and milk and the environmental impacts related to beef are lower than for beef produced from bull fattening. This explains the difference in the results in Opio (2013) between the dairy herd and the beef herd and the results in Alig (2012) between the bull fattening and the suckler cow.

Table 3.17 Literature review for beef (Landquist et al. 2013)

Reference	Country	kg CO_2-eq/kg beef	Remarks	System boundaries
This study, 2011	Romania	33.0	Dairy cattle producing meat and milk	at slaughterhouse gate with packaging
Crosson et al. 2011	Ireland	21.2 19.2 18.3	National steer-beef bull beef	
Williams et al. 2006	United Kingdom	15.8 18.2 25.3 15.6 16.4	national organic suckler lowland upland	
Cederberg et al. 2009	Sweden	28		
Veysset et al. 2010	France	30.5 26.6	Cow-calf integrated cow-calf to beef	
Nguyen et al. 2010	EU	27.3	Dairy bull calf dairy bull steer	
Alig et al. 2012	Switzerland	24.9 27.8 43.3 41.9	bull fattening PEP* organic bull fattening suckler cow PEP organic suckler cow	at slaughterhouse with packaging
Jungbluth et al. 2013	Switzerland	16.2 15.2	conventional organic	No packaging
Jungbluth et al. 2013	Argentina	11.3	conventional	No packaging, no slaughtering waste in the LCI
Opio et al. 2013	Global, FAO	24.5 90.4	Dairy herd Beef herd	

*Proof of Ecological Performance (PEP). Animals in bull fattening stem from milk production

3.4.2 Raw milk and beef

Allocation rules and comparison with literature values

The physical allocation between meat and milk in this study is based on a formula developed by the IDF (see section 3.1.5). However, this formula is valid for the US and may be different in a European context. An economic allocation can be made on the basis of the products' shares in the turnover but a physical allocation is better approved by the ISO standard. They suggest that an economic allocation should be chosen only if a physical relationship between the different products cannot be established (International

Organization for Standardization (ISO) 2006b). Therefore, the economic allocation is not investigated between meat and milk in this report. In Table 3.18, a literature comparison is performed on the allocation between milk and meat. For example, FAO (2013) follows an allocation approach based on the protein content in milk and meat, which results in a higher allocation factor for milk. The allocation factors given by Cederberg (2009) are in the same range as the ones used in this case study. It is therefore suggested to follow the IDF allocation approach in the SENSE tool when an allocation is necessary to allocate the environmental impacts to milk and beef produced.

Table 3.18 Comparison of literature values for the allocation between beef and raw milk

Reference	**Country**	**kg CO_2-eq/ kg raw milk**	**Remarks**	**kg CO_2-eq/ kg meat**	**Remarks**	**Allocation of impacts at the farm**
This study, 2013	Romania	1.06	per kg raw milk	33	per kg beef	physical allocation 80%/20%
Cederberg et al. 2009	Sweden	1.02 0.96	per kg ECM[3] per kg raw milk	19.8 26.4	per kg CW[1] per kg beef	Physical allocation 85%/15%
Jungbluth et al. 2013	Switzerland	0.83 0.74	per kg raw milk conventional organic	16.2 15.2	Per kg beef conventional organic	Economic allocation 87%/13%
Opio et al. 2013	Global FAO	2.8 2.8	per kg FPCM[2] per kg raw milk	18.4 24.5	per kg CW[1] per kg beef	Physical allocation 92%/8%

[1]CW:carcass weight. Conversion of carcass to bone-free meat is obtained by multiplying by 0.75
[2] FPCM: Fat Protein Corrected Milk kg FPCM=(0.337+0.116*fat%+0.06*protein%)* kg milk with 4% fat and 3.3% protein
[3]ECM: Energy corrected milk kg ECM=(0.256+0.073*protein%+0.124*fat%)* kg milk with 4.42%fat and 3.49%protein

3.4.3 Dairy products

Most relevant stages

It is difficult to identify the impact drivers since the results are quite different among the dairy products. However, since the raw milk input contributes in average 70% to the results, the impact drivers are quite similar to the ones for the beef production in the previous chapter and are shown in Table 3.19. The main difference is the higher contribution of the energy use at dairy plant since the energy used to process raw milk into dairy products is more intensive than the one to process cattle into beef. The share of lignite in the Romanian electricity mix is around 40% (Itten et al. 2012). The burning of lignite in power plant contributes to the climate change, the abiotic resource depletion and the freshwater eutrophication and to a smaller extent to the freshwater ecotoxicity and human toxicity cancer effects. Therefore, the impacts of the electricity use are more important.

The pasteurized milk, sour cream, yoghurt, curd and cream cheese packaging contribute to the abiotic resource depletion and climate change impact categories due to the material and energy use required for its production.

Table 3.19 Impact drivers for the dairy products at dairy plant

Impact category	Impact drivers	Key substances
Climate change	Enteric fermentation, agricultural machinery manufacture and use, energy use for dairy product processing, packaging	methane, carbon dioxide
Human toxicity, cancer effects	P2O5-fertiliser use, agricultural machinery manufacture, buildings and facilities, energy use for dairy product processing	chromium
Human toxicity, non-cancer effects	P2O5-fertiliser use, agricultural machinery use	zinc
Acidification	Manure application, cattle emission in open yard, agricultural machinery use, N-fertiliser	ammonia, nitrogen oxides
Eutrophication, terrestrial	Manure application, cattle emission in open yard, agricultural machinery use, N-fertiliser	ammonia, nitrogen oxides
Eutrophication, freshwater	Phosphate runoff and leaching from cultivated land, energy use for dairy product processing	phosphate
Eutrophication, marine	Manure application, N-fertiliser and agricultural machinery use	nitrate, nitrogen oxides
Ecotoxicity, freshwater	P2O5-fertiliser use, herbicide use, agricultural machinery use, buildings and facilities	chromium, zinc
Land use	Cultivated area	land
Abiotic resource depletion	Agricultural machinery fuel production, energy use for milking, energy use for dairy product processing, packaging	oil, lignite, gas
Water depletion	Water use at farm, agricultural machinery fuel production, milking, water use at dairy plant	water

Allocation rules

The results for single dairy products are quite sensitive to the allocation approach chosen. The allocation factors used in this study were modelled by the IDF (see section 3.1.5). So far, no updated version was published. It must be highlighted that the matrix developed is a “starting point that will be further developed in the future” as it is written in a footnote in the report (IDF 2010). Moreover, not all the dairy products produced at the Romanian dairy plant were available in the matrix and some allocation factors were applied to more than one dairy product. Therefore, some dairy products have the same environmental impacts, which may not be true in reality. Some inputs are also missing in the matrix, i.e. no allocation factors are available for the infrastructure and additional organic inputs. The environmental assessment would gain in accuracy with a more detailed allocation matrix available with this methodology with more dairy products and other organic inputs included.

The alternative allocation scenarios described in section 3.2.3 provide different raw milk input for each dairy product. This level of detail is an advantage compared to the IDF since the raw milk is the main contributor to the environmental impacts for all dairy products. The other resources are allocated based on the shares in turnover of each dairy product and this is a drawback compared to the IDF since the economic allocation is less favoured than an allocation based on physical relationships in the ISO standard (International Organization for Standardization (ISO) 2006b).

Another perspective that might be considered in the allocation approach is the nutritional values of different dairy products. Recommendations for nutrition are based on other characteristics of dairy products such as the calcium content. Such recommendations might also be a basis for an allocation as they define the functionality of different types of products.

It is so far difficult to assess which allocation method is the most appropriate. The following literature review should further help identifying which allocation approach can be recommended.

Comparison with literature values

Whole milk

The comparison of the global warming potential of the pasteurised milk assessed in this inventory with the literature review done in the WP1 of the SENSE project is shown in Table 3.20. The GWP of the Romanian pasteurised milk is the highest value among the other literature values when the IDF allocation approach (also name physico-chemical allocation) is applied. When the alternative allocation is applied, the GWP is also in the upper range of the other literature values. The main reason is the difference in the amount of raw milk input between both allocation approaches. The whole milk is sensitive to the allocation method. Therefore, it is important to know which allocation method was applied if results from different case studies are compared.

Table 3.20 Literature review for whole milk (Landquist et al. 2013)

Reference	Country	kg CO_2-eq/kg milk	System boundaries	Remarks
This study, 2011	Romania	1.93 1.45	IDF allocation Alternative allocation	PE bottle incl.
Fantin et al. 2011	Italy	1.3		
Castanheira et al. 2010	Portugal	1.0		
Flysjö et al. 2011	Sweden	0.99 0.73 1.02 1.16	IDF allocation System expansion Economic allocation All to milk	per kg ECM[1] at farm gate
Sheane et al. 2011	Scotland (UK)	1.4	cradle to grave	
Thomassen et al. 2009	Netherlands	1.28		
van der Werf et al. 2009	France	0.98-1.02		per kg FPCM[2]
Sevenster & Jong 2008	EU	0.75-1.65		national inventory reports/UNFCCC data
IDF 2009	Mostly European countries	1.0	not applying the IDF allocation approach	literature review
Jungbluth et al. 2013	Switzerland	0.75 0.67	whole milk at dairy whole milk, organic, at dairy	Packaging not included, allocation by fat content

[1]Energy corrected milk
[2]Fat and Protein Corrected milk

Cheese

The comparison of the global warming potential of the Romanian soft cheese assessed in this inventory with the literature review is shown in Table 3.21. IDF (2009) mentions that 10 kg of milk are necessary to produce 1 kg of cheese while the raw milk input is 6 kg in this case study for both allocation approaches. This could explain why the GWP of the Romanian cheese is lower than the literature values. The GWP of cheese is not as sensitive to the allocation method as it is for other products. Furthermore it has to be noted that different types of cheese might show quite different environmental impacts.

Table 3.21 Literature review for cheese (Landquist et al. 2013)

Reference	Country	kg CO2-eq/kg cheese	Remarks	allocation
This study, 2011	Romania	7.80 7.4	Soft cheese	physico-chemical allocation alternative allocation
Sheane et al. 2011	Scotland, UK	10.4	cheddar cheese	dry mass allocation
Nielsen et al. 2003	Denmark	11.9		
Berlin 2002	Sweden	8.8		
IDF. 2009	Mostly European countries	8.8		Average of different values
Jungbluth et al. 2013	Switzerland	11 3.49[1]	cheese mozzarella1	Fat content Dry mass allocation
Kim et al. 2013	US	7.3 8.5	mozzarella cheddar	dry mass allocation

[1]inventory of Kim et al 2013 re-modelled by ESU-services

Other dairy products

The comparison of the GWP of yoghurt , cream and butter with literature values is shown in Table 3.22. The GWP of the Romanian yoghurt is higher than other literature values when the IDF allocation is applied. If the alternative allocation is applied, the GWP is in the range of the other literature values. The lack of other literature values on butter and cream does not enable a sound discussion on the allocation approaches.

Table 3.22 Literature review for yoghurt and other dairy products

Reference	Country	kg CO2-eq/kg yoghurt	Allocation
This study, 2011	Romania	3.35 1.83	IDF allocation alternative allocation
González-García et al. 2013	Portugal	1.78	mass allocation
Sheane et al. 2011	UK (Scotland)	1.78	Dry mass allocation
IDF. 2009	Mostly European countries	1.1	Average of different values
Büsser & Jungbluth 2009b; Jungbluth et al. 2013	Switzerland	1.13	Fat content
		kg CO2-eq/kg cream	
This study, 2011	Romania	5.66 6.87	IDF allocation alternative allocation
Sheane et al. 2011	UK (Scotland)	4.7	Dry mass allocation
Jungbluth et al. 2013	Switzerland	7	Fat content
		kg CO2-eq/kg butter	
This study, 2011	Romania	10.5 24.2	IDF allocation alternative allocation
Sheane et al. 2011	UK (Scotland)	7.7	Dry mass allocation
Büsser & Jungbluth 2009a; Jungbluth et al. 2013	Switzerland	16.2	Fat content

Recommendation for the SENSE tool

The evaluation of the available literature for whole milk further highlighted the importance of the allocation approach chosen. There are fewer LCA studies on butter, cream and other kind of cheese such as fresh cheese and cream cheese. Moreover, there are very little LCA studies on the assessment of a dairy plant producing more than two or three dairy products. Therefore, the allocation approach has never been discussed for a dairy plant producing such a variety of dairy products.

The allocation approaches discussed in the previous sections require different types of information, i.e. fat content, protein content, dry mass content, share in annual turnover or a pre-defined physic-chemical allocation matrix. All type of information could be stored with default values in the tool or could be provided case specific by the plant operator which could make the calculation more accurate.

Our experience with the IDF matrix is that it might be more complicated to be integrated in the tool because it needs some interrelated background calculation. The allocation factors are different for each resource use, i.e. raw milk, electricity, natural gas, water, detergents, transport.

A simpler alternative is to use a dry mass content allocation for the raw milk input and use the shares in the annual turnover for all other resources consumed at plant. In order not to increase the amount of data entered by the operator, it is suggested to have the dry mass content and the average European prices of different types of products in the background data of the tool. This approach is recommended for the SENSE tool.

3.4.4 Impact assessment for toxicity

All impact assessment results in this case study are differentiated between the human toxicity, cancer effects and the human toxicity, non-cancer effects. There are some relevant differences between the impact assessment results of these two effects. For example, the contribution of the construction materials is higher to the cancer effects (see Figure 3-3). Moreover, the contribution of the electricity use for the yoghurt processing at the dairy plant to the cancer effects is higher than its contribution to the non-cancer effects due to the lignite disposal (see Figure 3-14). Hence, it is suggested to only assess the human toxicity, cancer effects in the SENSE tool.

The impact category ecotoxicity freshwater assessed together the heavy metals and pesticides. The characterisation factors for the heavy metals are classified as “uncertain” while the ones for the pesticides are “recommended”. It would be possible to separate the assessment of the heavy metals in order to better interpret the impact assessment of the pesticides, but this has not been foreseen according to D. 1.3 in work package 1 (Aronsson et al. 2013).

3.4.5 KEPIs

In this chapter a set of key environmental performance indicators (KEPIs) for the beef and dairy product system is suggested. The KEPIs are selected based on the impact drivers identified in the previous section. The KEPIs for the beef and dairy products are listed in Table 3.23. They are separated into the five major production steps: fodder production, livestock, milking, slaughtering and dairy plant that are written horizontally at the top of the table. Each KEPI is given a name and a unit. The list of KEPIs is displayed below the production steps. Each KEPI is assigned to each corresponding production step. On the right side, the impact categories are listed vertically. When the contribution of the KEPI to an impact category is relevant, the cell is coloured in red. The red cell is either filled with a cross or with the main pollutant emitted by the KEPI, e.g. carbon dioxide, heavy metals, ammonia, phosphate, etc.

Fodder production

The fodder production corresponds to the crop cultivation, which requires the use of fertiliser, manure, liquid manure, pesticide, agricultural machinery, land, water and storehouse.

The KEPIs **N-fertiliser use** and **P2O5-fertiliser use** refer to the production and use of these fertilisers. It is important to differentiate between the types of fertilisers applied on crops. The N-fertiliser has a higher contribution to the climate change, acidification, terrestrial and marine eutrophication whereas the P_2O_5-fertiliser contributes mainly to the human toxicity, freshwater ecotoxicity and the freshwater eutrophication. Therefore, it is important that the farm gives the amounts applied separately. The production and the emissions to air, soil and water are covered in the background system and not asked to the farm.

The KEPI **manure and slurry application** refers to the manure and liquid manure (or slurry) applied on crops and are determinant for the climate change, acidification, terrestrial and marine eutrophication. The farm provides the application rate and the emissions to water and to air are included in the model.

The KEPI **Pesticide and active substance content** includes the production of pesticides and the emissions from the active substances contained in the pesticides applied. It is important that the farm provides the pesticide name and the content of active substance. If the latter is not known, it can be found in literature. The active substances are necessary to estimate the emissions that affect the freshwater eutrophication and ecotoxicity. In a similar way as for the fertilisers, the production of pesticides is included in the background system.

The KEPI "**diesel use incl. machineries**" refers to the diesel consumption including its production and the agricultural machineries used. The diesel production and the emissions resulting from use are included in the background system. The CO_2 emissions due to combustion of fuels can be directly calculated with the amount of fuel burned. The agricultural machinery fleet contributes to the human toxicity and ecotoxicity impacts as well as the freshwater eutrophication. It can be difficult for a farm to estimate its agricultural machinery fleet. It is suggested to have an estimation of the agricultural machinery as a background process linked to the diesel consumption, as it was done also for this case study. Indeed, the diesel use for the agricultural processes is modelled with a dataset that includes the diesel fuel consumption, the corresponding amount of agricultural machinery needed (tractor, trailer, harvester, tillage) and its production and the shed corresponding to the machinery use.

The **arable land use** and the **grazing land use** are KEPIs for the land use impact category. The land use includes the emissions of phosphorus to water that affect the freshwater eutrophication.

The **direct water use** is also a KEPI related to the water depletion impact category.

The construction of the farm buildings affects mainly the human toxicity due to the impacts of the construction material production. The farm should provide the **area of the storehouse**. The office buildings can be omitted based on the experience in this case study.

It has to be noted that in our case study fodder was produced on the same farm as the animals. If animal feed is bought on the market the relevant KEPIs have to be investigated for the production of all the different type of feed bought by the farm, e.g. soy bean, maize, by-products of food and bioenergy production etc.

Livestock

The farm should provide the herd size and the shares of dairy cow, bull, calf, suckler cow. This is covered in the KEPI **herd size**. It determines the fodder production, the manure and slurry production and the milk and animals sold to the slaughterhouse. By giving the **cattle average weight** in each category and the raw milk production together with its **fat content** and **protein content**, the livestock emissions of methane and ammonia can be estimated. This is the reason why these three parameters are considered as KEPIs. The **feed efficiency** is also an important parameter to compare different kind of feeding system. This information was however not available for our case study.

The KEPI **animals sent to slaughtering** and **raw milk production** together with the **protein and fat content** are needed for the allocation approach. The farm should also give the **area of the cattle housing**. The construction materials affect mainly the human toxicity and ecotoxicity.

Milking

The milking is the process of removing milk from the dairy cows. The KEPIs **electricity use** and **water use** were identified for this process. The electricity use covers the electricity production. However, environmental impacts of electricity production vary from country to country. Consequently different impact categories might be affected by the electricity use if case studies are elaborated in another country.

Slaughtering

The KEPIs **meat production** and **meat waste** should be provided by the slaughterhouse in order to allocate the slaughtering process to the production of beef and assess the meat yield, i.e. the ratio of meat per livestock animal. Our case study includes the slaughtering waste treatment with background data.

Dairy plant

The dairy plant does not only comprise the infrastructure but the whole process of transforming raw milk into dairy products. The **raw milk input** as well as the **electricity use**, **thermal energy use** and **water use** can be given on a whole of factory basis and allocate to each dairy product thank to the allocation approach applied, e.g. the IDF matrix (see section 3.1.5). Furthermore the produced amount of each single **dairy product** has to be reported. The infrastructure of the dairy plant could be included in the background data related to the raw milk input processed at the dairy plant. It is also important to know the **packaging material** and its weight especially for the milk PE bottle and the yoghurt. The production of the packaging should be included in the background system.

Transportation

In this case study transportation distances between farm and further processing were quite small. There are also not major transports of fodder products to the farm. Therefore impacts due to transportation were not found to be a major issue and are not considered in the definition of KEPIs. This conclusion might not be valid for cases with higher transportation distances involved between processing stages.

Table 3.23 List of proposed KEPIs for beef and dairy products for each impact category and the main pollutants concerning a specific impact category and influenced by a specific KEPI.

Impact category	Fodder production									Livestock							Milking		Slaughtering		Dairy processing					Main pollutants
Unit	kg-N/ha	kg-P2O5/ha	kg/ha	kg/ha	l/ha	ha	ha	m3/ha	m2	number and categories	kg live weight/category	kg raw milk/dairy cow	%	%	kg feed/kg live weight	number/category	kWh/kg raw milk	m3/ kg raw milk	kg meat/kg live weight	kg waste/kg meat	kg raw milk/kg product	kg product /category	MJ/kg raw milk	kg/kg product	m3/ kg raw milk	
Key Environmental Performance Indicator (KEPI)	N-fertiliser use	P2O5-fertiliser use	Manure and slurry application	Pesticide and active substance content	Diesel use incl. machineries	Arable land use	Grazing land use	Water use	Buildings	Herd size	Cattle weight	Raw milk production	Raw milk fat content	Raw milk protein content	Feed efficiency	Cattle to slaughtering	Electricity use milking	Water use milking	Meat production	Waste	Raw milk input	Dairy products	Thermal energy	Packaging material	Water use	
All impact categories										x	x	x	x	x	x	x			x	x	x	x				
Climate change	N2O		N2O		CO2					CH4							CO2						CO2	CO2		CO2, CH4, N2O
Human toxicity		HM			HM				HM																	Heavy metals (HM)
Acidification	NH3		NH3		NOx					NH3																NOx, NH3
Eutrophication, terrestrial	NOx		NH3		NOx					NH3																NO3, NH3
Eutrophication, freshwater		PO4		PPP	PO4	PO4	PO4																			PO4
Eutrophication, marine	NO3		NO3		NOx																					NO3 (Nitrate), NOx
Ecotoxicity, freshwater		HM		PPP	HM																					Heavy metals (HM) Plant Protection Products (PPP)
Land use						x	x																			Land use (m2a and type)
Abiotic resource depletion	x	x		x	x				x								x						x	x		Fossil resources (oil, gas, coal)
Water depletion					x			x										x							x	Water use

The contribution of the KEPIs to the overall environmental impacts for the beef assessment is shown in Figure 3-18.

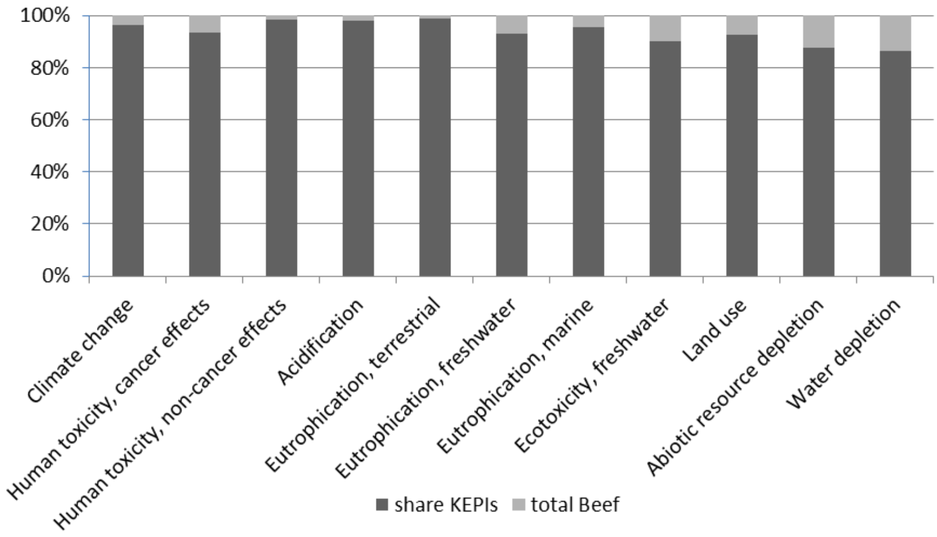

Figure 3-18 Share of the environmental impacts covered by the KEPIs selected for the beef assessment

The contribution of the KEPIs to the overall environmental impacts for the assessment of pasteurised milk is shown in Figure 3-19.

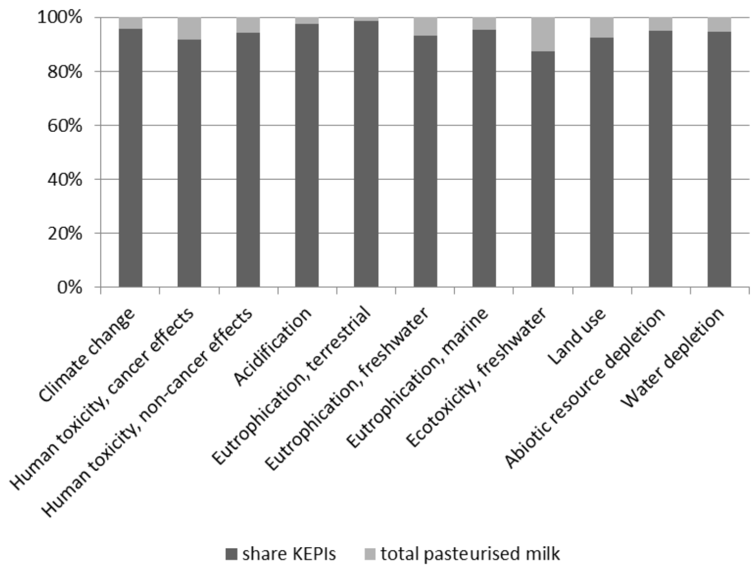

Figure 3-19 Share of the environmental impacts covered by the KEPIs selected for the pasteurised milk assessment

3.4.6 Regionalisation

An important question of the project is the adjustment of the SENSE model to regional characteristics. For each impact category, the KEPIs have already been identified in Table 3.23. Depending on this, it can be evaluated whether a regionalised impact assessment, a regional emission model or regional background data is needed and available to improve the quality and reliability for a regionalised assessment. The Table 3.24 lists the influencing factors for a regional assessment.

The regionalisation of the **impact assessment method** (LCIA) means that different characterization factors are used for each country or for a specific region. The characterisation factors of ammonia, nitrogen oxides and sulphur dioxides for acidification in Romania are available and they are smaller than the weighted average characterisation factors implemented in SimaPro. The characterisation factors of ammonia and nitrogen oxides for terrestrial eutrophication in Romania are higher than the weighted average implemented in SimaPro (Posch et al. 2008). In this assessment we already applied a regionalised approach for water depletion (Flury et al. 2012). Furthermore it would be relevant to better differentiate the impacts of different types of land occupation which is not possible with the LCIA method used so far.

Several calculations for direct emissions due to the application of fertilizers and the animal rearing are based on scientific **emission models** and not on real measurements. One issue of the regionalisation is to assess the possibility of having emission models that can be directly feed with data provided by the SME and thus better considering the local circumstances. Some of the models used in this case study are based on regional experiences e.g. in Switzerland. In principle the outcome of these calculations can be influenced by regional circumstances such as rainfall, soil quality, slope of fields, average temperatures, irradiation, etc. Therefore it would be necessary to better adapt the models to the specific regional situation. But, such easy-to-apply models for the whole of European regions are so far not available. Therefore we only applied a case specific model for the methane emissions of the animals on the farm according to the tier 2 approach of the IPCC. This emission model is now specific to the Romanian dairy farm (milk yield, animal mature weight, feeding situation etc.). A quite relevant question for a regionalised model would be the calculation of phosphate emissions from erosion and run-off at agriculture areas as well as different type of nitrogen emissions due to fertilizer, manure and dung use. The modelling of NOx emissions from fuel combustion, which depends e.g. on the technology standards applied in a specific region, could be another issue for a regionalized model.

The background system is not under the direct influence of the SME but it is the basis of the SENSE tool. In many cases LCI background data are just available for a global or a European production mix. But, in practice the markets in different regions might be supplied with a different mix of products. Thus, also LCI data can be adapted to the market situation in a specific region. The easiest regionalisation of **background LCI data** is the application of a country-specific electricity mix. Datasets are publicly available and can be easily implemented (Itten et al. 2012). Water use can also be inventoried country-specific. For others background data we do not expect major differences (diesel, natural gas, fuel oil) in the environmental impacts or it might be very time consuming to further elaborate such regionalized data e.g. for machinery production and buildings.

Table 3.24 Identification of regionalisation potentials in impact assessment methods, emissions model and background data based on the case study for beef and dairy products

Impact category	**Regional impact assessment methods**	**Emission model**	**Background data**
Climate change	Not relevant	CH_4 direct emissions herd size CO_2 emissions diesel use CO_2 emissions thermal energy	Electricity mix Agricultural machinery production Packaging production
Human toxicity	Not available	Not relevant	Agricultural machinery production Buildings and facilities construction Electricity mix Chromium content in P2O5-fertiliser
Acidification	Regional characterisation factors available	NH_3 and NOx emissions manure application NH_3 direct emissions herd size NOx emissions diesel use	Electricity mix
Eutrophication, terrestrial	Regional characterisation factors available	NH_3 and NOx emissions manure application NH_3 direct emissions herd size NOx emissions diesel use	Not relevant
Eutrophication, freshwater	Not available	Phosphorus emissions arable and grazing land use	Electricity mix
Eutrophication, marine	Not available	NO3 emissions N-fertilizer use NO3 and NOx emissions manure application NOx emissions diesel use	Not relevant
Ecotoxicity, freshwater	Not available	Active substance emissions to soil (herbicide use)	Agricultural machinery production Buildings construction Electricity mix Packaging production Heavy metal content of P2O5-fertiliser Zinc emissions from machinery use (tyres)
Land use	No LCIA method yet	Type of land occupation	Not relevant
Abiotic resource depletion	Not relevant	Not relevant	Electricity mix Diesel production Thermal energy production Packaging production Buildings construction
Water depletion	Regional characterisation factors used	Direct water use	Electricity mix Water resources used for tap water P2O5-fertiliser production Agricultural machinery production

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Annex Life Cycle Assessment Methodology

The life cycle assessment (LCA) – sometimes also called ecobalance – is a method to assess the environmental impacts of a product[6] encompassing the whole life cycle (cradle to grave). Hence, the environmental impacts of a product are evaluated from resource extraction to material production, product manufacturing, use of the product up to the disposal of the product and also the production wastes.

The general procedure of conducting an LCA is standardised in ISO 14040 (International Organization for Standardization (ISO) 2006a) and ISO 14044 (International Organization for Standardization (ISO) 2006b)

An LCA consists of the following four phases (Figure 1):

1. Goal and Scope Definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

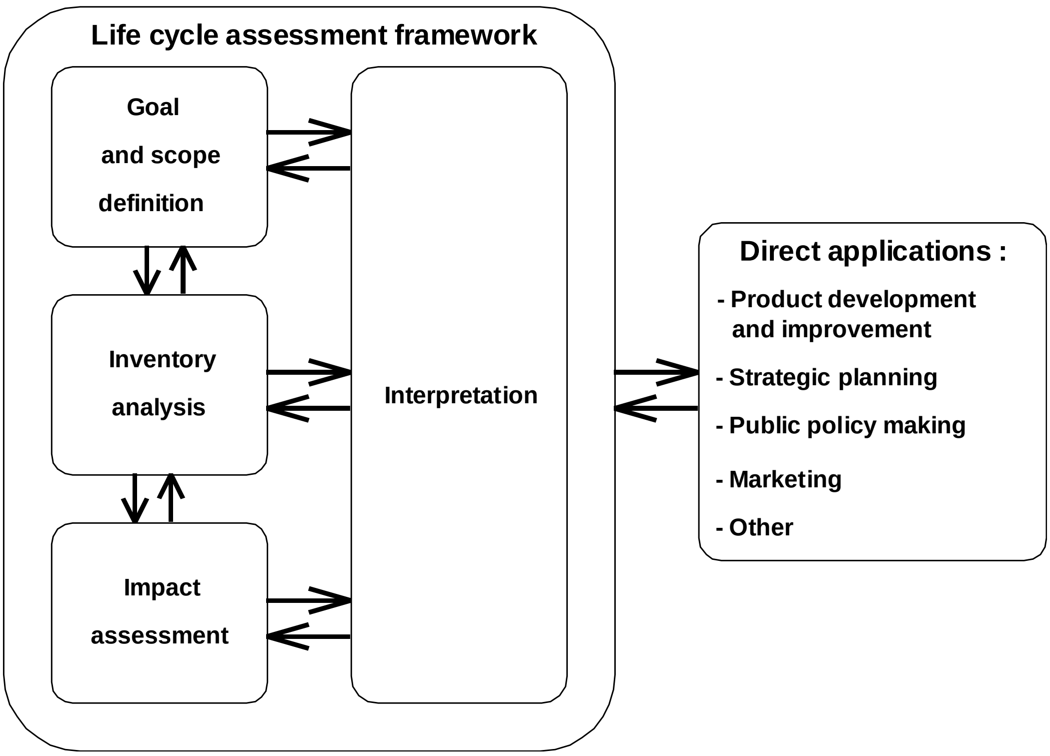

Figure A.1 The four phases of the life cycle assessment (LCA) framework according to International Organization for Standardization

The *Goal and Scope Definition* (phase 1) includes a description of the goal of the study and covers the description of the object of investigation. The intended audience is determined. The environmental aspects

6 The term product also encompasses services

to be considered in the impact assessment and the interpretation and the functional unit, to which all emissions and resource uses are referred to and which determines the basis for the comparison, are defined.

The elementary flows[7] occurring in a process, the amount of semi-finished products, auxiliary materials and energy of the processes involved in the life cycle are determined and inventoried in the *Inventory Analysis* (phase 2). These data are set in relation to the object of investigation, expressed by the functional unit. The final outcome consists of the cumulative resource demands and the cumulative emissions of pollutants.

The Inventory Analysis provides the basis for the *Impact Assessment* (phase 3). Applying current impact assessment methods, such as climate change impact according to IPCC (2007), on the inventory results leads to impact indicator results that are used and referred to in the interpretation.

The results of the inventory analysis and the impact assessment are analysed and commented in the *Interpretation* (phase 4) according to the initially defined goal and scope of the LCA. Final conclusions are drawn and recommendations stated.

[7] Resource extraction and emission of pollutants