Milk Processing – Life cycle assessment of a detailed dairy model and recommendations for the allocation to single products

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ABSTRACT

This study analyses the environmental impacts referring to dairy products and to the operation of a dairy. The analysis is based on a detailed, product-specific model calculation. The environmental impacts are analyzed from cradle to gate including and excluding the raw milk input. The environmental impacts are assessed with the midpoint methods suggested by ILCD.

The detailed dairy model allows the assignment of inputs and outputs for each sub-process to single dairy products and thus avoids allocation to a large extent. The analysis of the model dairy shows that raw milk production has the main impact in all categories. Consumer packaging has the second biggest impact in many categories.

The analysis of inputs to the different dairy products per kilogram shows that UHT milk uses more chemicals for cleaning compared to the other products. Cream uses more electricity and heat compared to UHT milk and to yogurt. This is in contrast to the allocation suggestion of Feitz et al. (2007). The allocation of chemicals, steam and electricity can be undertaken based on the detailed dairy model developed in this study.

Keywords: dairy, milk products, carbon footprint, allocation, milk processing

1. Introduction

The inputs and outputs of dairy processing are usually only available for the whole plant. There is little information about the assignment of different inputs and outputs to the single dairy products. This assignment is important since it greatly influences the impacts assigned to each dairy product.

In the European SUSMILK project, a detailed bottom-up modelling of a theoretical generic dairy was compiled with the product portfolio given in Table 1 (Maga and Font Brucart 2016). The model of Maga et al. gives the inputs and outputs for more than 40 production sub-processes in the dairy (i.e. separation, pasteurization) and a detailed modelling of CIP (clean in place) for each machinery involved. This model was complemented with additional inputs to account for all inputs of the dairy operation from cradle to gate[1] and results in the LCA dairy model (Jungbluth, Keller et al. 2016).

Table 1: Daily amount of raw milk input and dairy products output produced in the LCA dairy model (kg/d).

	Flow name	Packaging	Amount
Raw milk input	Raw milk (4,2 % fat)	None	618'387
Dairy products	UHT[2] milk (3,5 % fat)	Tetra Brik 1 l	103'125
	Stirred yogurt (10 % fat)	Polypropylene cup, 0.15 l	25'959
	Cream (30 % fat)	Tetra Brik 0.25 l	20'022
	Concentrated milk (0,2 % fat)	None	121'337
	Cream (40 % fat)	None	29'609

With the LCA dairy model, the environmental impacts of process stages of dairy processing are analyzed from cradle to gate related both to the daily dairy operation as well as to different products.

The analysis of several improvement options (heat provision, cooling) is described in a detailed life cycle assessment to be published for this project (Jungbluth, Keller et al. 2016). Improvement options that were only analyzed in lab scale were not integrated in the LCA dairy model.

[1] Additional inputs are i.e. packaging material, infrastructure and additional water and electricity inputs.

[2] UHT stands for Ultra-high-temperature processing. The milk is heated to 140°C.

Finally, the allocation of the inputs calculated according to the dairy model is compared to the allocation method suggested by the IDF (IDF 2010, based on Feitz, Lundie et al. 2007) and the differences in results are discussed.

2. Goal and Scope

This paper aims to show how relevant energy and water uses as well as different process stages in a model dairy are from an environmental point of view. It also aims to show the relevance of these process stages relating to the single dairy products at gate. The third aim is to present a way of allocation of dairy inputs onto different products, based on the detailed dairy model and compare these results to the recommendation of the International Dairy Foundation.

The scope of the LCA is from cradle to (dairy) gate, including the treatment of waste (i.e. waste water) up to gate plus post-consumer waste of packaging. One kilogram of processed raw milk is used as functional unit for the analysis of the dairy. This allows a comparison of dairies with different production volumes and product portfolios. The reference flow is one day of operation of the dairy model (600'000 liter raw milk). The functional unit for the analysis of the products is 1kg of dairy product. The LCA does not aim to compare different products or dairies directly.

The cumulative life cycle inventory data is assessed with impact assessment categories recommended by the ILCD at midpoint level (European Commission, Joint Research Centre et al. 2010).

3. LCI

The detailed dairy model was developed together with project partners, based on literature and estimations from dairy experts (Maga and Font Brucart 2016). All internal streams of the processing for single products (see product portfolio in Table 2) as well as of steam (heat provision), cold water (cooling) and electricity are modelled.

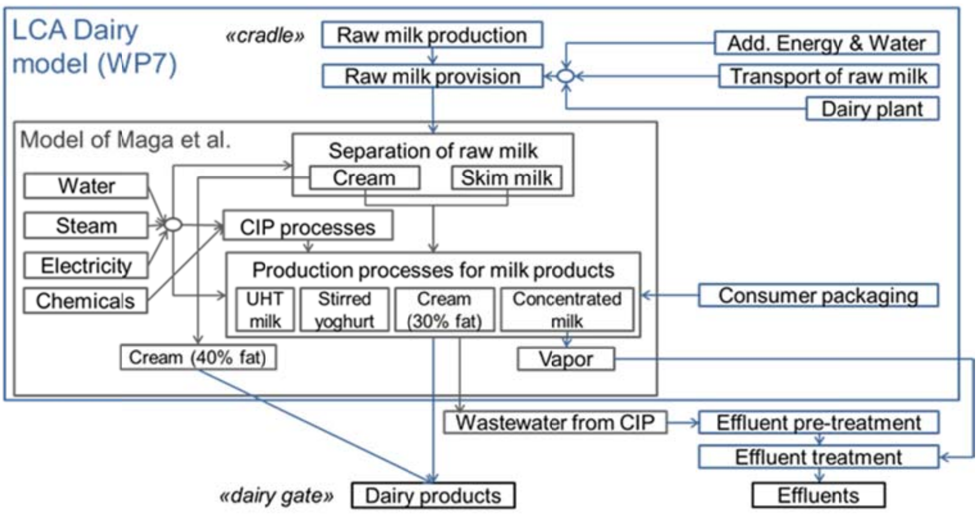

Figure 1 System boundaries and simplified model design of the LCA dairy model on milk processing. The inputs (i.e. steam, water) are specific for the respective dairy products. Circles are used to collect and redistribute the various inputs to the five products.

Table 2: Properties of the products of the model dairy, given in mass percentage

Product	Raw milk	UHT milk	Stirred yogurt	Cream (30% fat)	Concen-trated milk	Cream (40% fat)	Skim milk
Water	87.10	87.73	80.56	63.45	68.25	54.55	90.87
Fat	4.20	3.50	10.00	30.00	0.20	40.00	0.05
Protein	3.30	3.33	3.58	2.42	11.97	2.07	3.44
Milk solids	12.90	12.27	19.44	36.55	31.75	45.45	9.13

The inputs of the dairy model are grouped into process stages for analysis (see Table 3), both according to aspects with high impacts (i.e. consumer packaging) and distinctions important for dairy producers (chemicals, electricity for production and for additional use).

Table 3: Name of the process stages used for analysis and the description of their main inputs.

Name of the process stage	Description
Raw milk production	Input of raw milk for processing excluding purchased products (e.g. milk powder)
Purchased products; dairy plant; additions	Purchased ingredients (e.g. milk powder), infrastructure of dairy plant, additional inputs (i.e. water and detergents; excluding additional electricity)
Transport of raw milk	Refrigerated transport of raw milk to the dairy
Effluent (pre-)treatment	Treatment of wastewater inside and outside the dairy, excluding electricity for pre-treatment as this is included in "Electricity, additional"
Consumer packaging	Product packaging (production and disposal)
Electricity, additional	Additional electricity use according to the LCA dairy model based on average literature data for electricity consumption of dairies minus "Electricity" as covered in the generic dairy model.
Electricity	Electricity use for production and the packaging process plus estimated use for lighting and compressed air according to the modelling in the generic dairy model
Steam for production /CIP[3]	Heat use delivered by steam for production / for CIP
Chemicals	Chemicals used for CIP
Water use	All inputs needed for water use and cooling, including refrigerants, infrastructure, excluding electricity use

Table 4 shows important inputs and outputs of the LCA dairy model that includes packaging material, raw milk input and wastewater treatment plus additional water and electricity use. The additional inputs are added to the dataset of the raw milk provision (Jungbluth, Keller et al. 2016). The ecoinvent database and available updates, as well as ESU data-on-demand are used as a background database (ecoinvent Centre 2010; ESU 2016; Jungbluth, Meili et al. 2016). The raw milk separation step[4] is allocated with milk solids (given in Table 2) as suggested by the IDF (IDF 2010) and Feitz et al (2007).

[3] CIP means "Clean-in-Place" and is a method of cleaning the interior surfaces of machinery (e.g. pipes, vessels, process equipment) without disassembly.

[4] Raw milk is separated into cream, 40% fat with a content of milk solids of 0.45 (weight per weight) and pasteurized skim milk, 0.05% fat with a content of milk solids of 0.09.

Table 4: Inputs per kg of product given by the LCA dairy model.

	Raw milk	Water use	Electricity	Steam use	NaOH 50 %	HNO3 70 %	Waste water
	kg	kg	MJ	MJ	G	g	l
UHT milk (3.5% fat)	1.0	1.2	0.3	0.4	6.070	1.086	1.261
Stirred yogurt (10% fat)	1.4	1.8	0.5	0.6	1.325	0.096	1.776
Cream (30% fat)	2.9	2.7	0.8	0.8	0.002	0.000	0.003
Concentrated milk (0.2% fat)	2.7	2.8	1.0	2.4	0.012	0.004	0.005
Cream (40% fat)	3.6	2.4	0.8	0.7	1.709	0.124	2.364

4. LCIA

Raw milk production has the highest share of impact in a cradle to gate analysis, varying from about half (water depletion, ozone depletion) up to almost hundred percent in the different impact categories. Raw milk production is therefore decisive for the environmental impact of the dairy products. But, this aspect lies outside the scope of the project and this LCA and it has therefore not been further investigated in detail.

The analysis of the dairy operation excluding the raw milk production[5] shows that the crucial process stage depends on the impact category (see Figure 2). The transport of raw milk (refrigeration truck) shows the highest share for acidification, ozone formation and terrestrial eutrophication. The consumer packaging has considerable shares in land use, particulate matter, abiotic resource depletion and all toxicity categories. The effluent treatment is most important for marine and freshwater eutrophication. The chemicals used for cleaning (NaOH, HNO3) have very little effect compared to the other process stages.

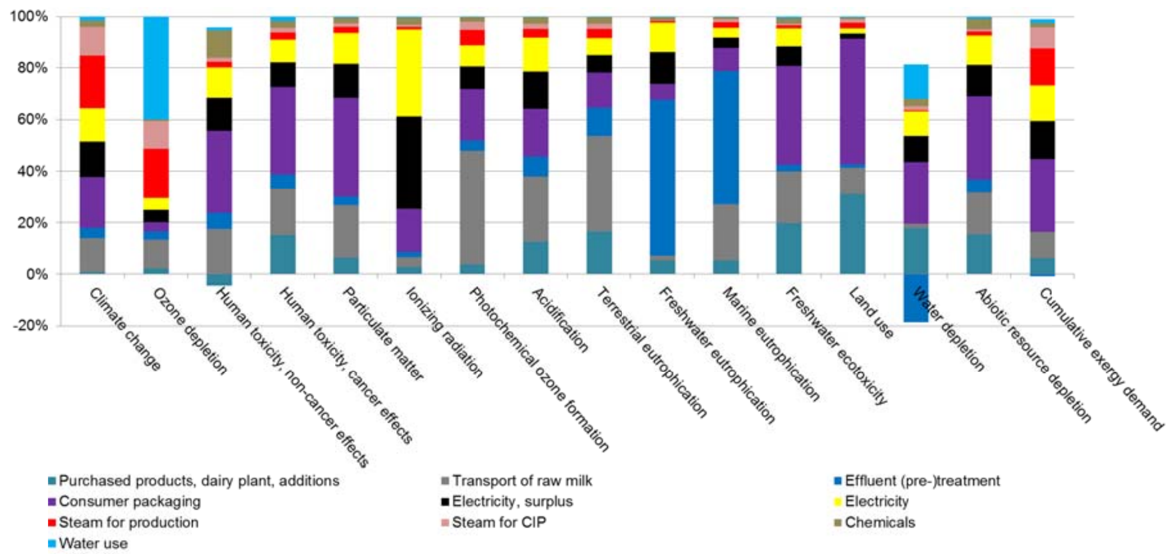

Figure 2 ILDC impact categories: Analysis of the dairy operation per day without the raw milk production and without allocation to single products. Percentage share of each process stage on the total impact in each category is depicted.

In the impact category climate change, the main impact stems from packaging of the UHT milk and cream (30% fat) which amount to 16% of the impact. When analyzing the packaging, around half stems from production and disposal of plastic parts and less than 20% each stem from the production

[5] The model for operation includes water and waste water treatment, energy, wastes, packages incl. their disposal, infrastructure and the transport of raw milk.

of aluminum foil and cardboard. Second highest impact is the steam for production (20%), followed by steam for CIP (11%).

In the impact category water depletion, around 40% stems from packaging[6]. Almost 30% stems from additional water and electricity use that is added in the LCA dairy model. The discharge of water after the "effluent (Pre-) treatment" shows a negative percentage since for this stage as it gives back water to the environment. The water in the effluent stems from vapors from concentrated milk, tap water input and from CIP. All water input is shown in the process stage "water use" and amounts to 21% of total impact in this category. Thus, the output of water after treatment is subtracted in the water balance from all inputs of water.

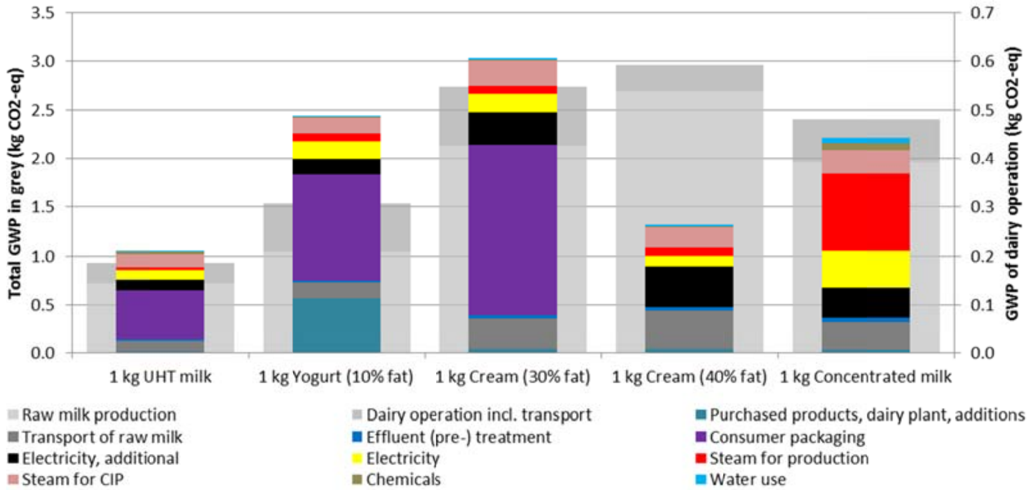

Figure 3 Comparison of impact on climate change (global warming potential, GWP) of dairy products at dairy gate. Grey columns in the background show the total GWP (cradle-to-gate), split into raw milk production and dairy operation (left axis). Coloured columns show the subdivision of the dairy operation (gate-to-gate) according to process stages (right axis).

[6] For Tetra Brik, the water use stems from paper production, for the polystyrene packaging of the yogurt, the cooling water used for thermoforming has the main impact

Also when referring the impacts on climate change to the different dairy products, raw milk prod (see

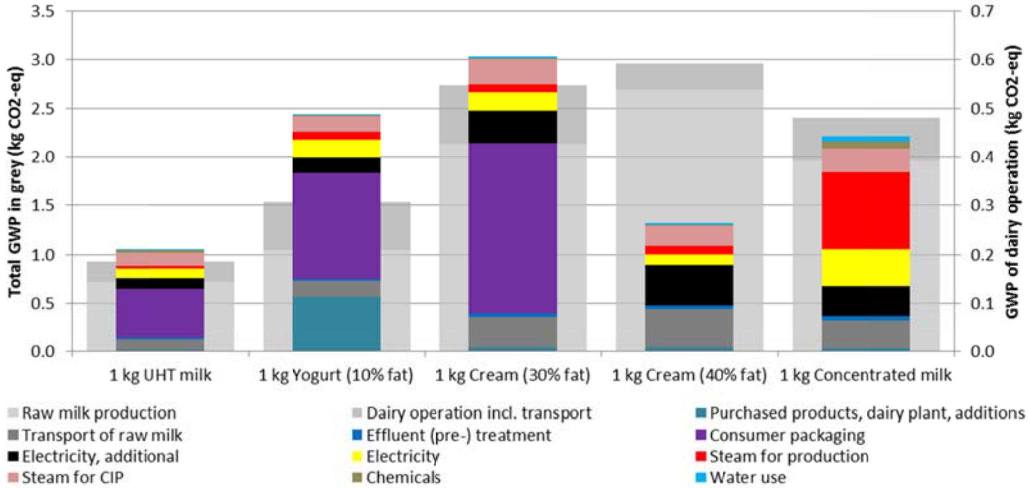

Figure 3). The allocation of raw milk and of the separation step is conducted according to milk solids. Thus for climate change, the products with the highest milk solids content have the highest impacts. The concentrated milk has lower impacts than the cream due to this allocation choice. Steam for preheating the milk and for evaporating has the main impact for the unpacked concentrated milk, whereas for the unpacked cream (40% fat), the electricity (used for processing and electric cooling) has the main share. The share of electricity (for production plus additional uses, without waste-water treatment) varies from 14% to 40% of the climate impact, the transport of raw milk from the farm to the dairy contributes 6% to 30%.

5. Interpretation

5.1 Main results

The main impact of dairy products stems from the raw milk input. Therefore, the production systems used for the raw milk have a decisive role for the overall environmental impact of dairy products and should be given priority in environmental improvement strategies.

For the dairy operation, the amount of packaging used and an efficient transport of the raw milk to the processing plant are important, as well as an adequate waste water treatment. Energy and water uses in the dairy are of minor importance in most impact categories, but for climate change, the heat demand contributes most to the total impact.

The shares of impact of process stages are very different for the five considered dairy products. The importance of each process stage changes depending on the processing conducted. For impact on climate change of concentrated milk, the steam (i.e. heat) use should be given priority. An intelligent process design that reuses heat within the dairy and an efficient evaporation can be used to decrease heat demand. For yogurt production, the milk powder has an important share even though the respective input is less than 2% of the total yogurt weight[7].

5.2. Allocation

Feitz et al. (2007) elaborated an allocation approach based on whole-of-plant data from 17 dairies. First, they collected total input data of dairies that only produce few products, like milk and cream.

[7] This is due to the allocation behind the milk powder that is conducted based on milk solid content.

Later, they subtracted these values from the total input of dairies with a wider product portfolio. Finally, an allocation matrix for dairy products was elaborated that can be applied to whole-of-plant data of dairies with various product portfolios. This approach is part of the IDF recommendation for allocation (IDF 2010, Chapter 6.3.4).

Table 5 first shows the input per kg of market milk according to the model dairy used in the publication of Feitz et al. (Table 5a). Next, the allocation of the sum of inputs for these three products from the LCA dairy model with the method of Feitz et al. is shown (UHT milk in Table 5b and all three products in Table 6b).

The inputs per kg of market milk in the model dairy of Feitz et al. (Table 5a) are similar to the inputs of UHT milk in the LCA dairy model (Table 5b). An exception is the chemical input. There, a much higher amount is modelled in the LCA dairy model compared to Feitz et al.

Table 5: Inputs per kg of market milk from the model of Feitz et al. and per kg of UHT milk for the LCA dairy model.

a) Input per kg of market milk according to the model dairy of Feitz et al. (2007)					
	Raw milk	*(Waste) water*	*Electricity*	*Fuel*	*Alkaline*
	kg	l/kg	MJ	MJ	G
Market milk	1	1.5	0.2	0.3	0.8
b) Allocation of the generic dairy inputs (3 products) according to Feitz et al. (2007)					
	Raw milk	*Water use*	*Electricity*	*Themal energy*	*Alkaline cleaners*
UHT milk (3.7% fat)	1.1	1.3	0.4	0.5	4.5

Table 6 shows the allocation of Feitz et al. (Table 5a) and compares this to the allocation conducted in the LCA dairy model (Table 5b). It shows that not only the amount of chemicals used for UHT milk is higher in the LCA dairy model compared to the allocation according to Feitz et al., but also the share allocated to UHT milk is higher. In Feitz et al, the same share is suggested for these products. According to Feitz, the resolution in their study was not high enough to identify i.e. different cleaning figures for UHT milk and for fresh milk[8]. The values used in the LCA dairy model are specific to the products. They are calculated by defining cleaning programs for different operations based on literature data (assumptions are described in detail in Maga et al. 2016). The UHT unit and evaporator for the concentrated milk require longer cleaning programs and higher concentrations of chemical products. Plus, recirculation of chemicals and rinse water is not carried out. Since our model shows much higher inputs for UHT milk, there seems to be a substantial difference in chemical use between UHT and normal milk that should be taken into account. Therefore the SUSMILK model is more detailed for allocation for these inputs and could be used to further improve allocation recommendations.

[8] Feitz, Andrew. Personal communication via e-mail on 14.4.2016.

Table 6: Inputs per kg of product with the allocation proposed by Feitz et al. (2007) for the 3 products yogurt, cream (40%) and UHT milk (6b) and inputs given by the LCA dairy model (6c).

a) Allocation of the generic dairy inputs (3 products) according to Feitz et al. (2007)							
	Raw milk kg	*Water use* kg	*Elec-tricity* MJ	*Themal energy* MJ	*Alkaline cleaners* g	*Acid cleaners* g	*Waste water* l
Yogurt (0.2/3.4% fat)	1.2	2.5	1.0	0.8	4.5	0.745	2.535
Cream (40% fat)	3.6	1.3	0.2	0.2	4.5	0.745	1.358
UHT milk (3.7% fat)	1.1	1.3	0.4	0.5	4.5	0.745	1.358

b) Inputs according to the LCA dairy model							
	Raw milk	*Water use*	*Elec-tricity*	*Steam use*	*NaOH 50 %*	*HNO3 70 %*	*Waste water*
Yogurt (10% fat)	1.4	1.8	0.5	0.6	1.325	0.096	1.776
Cream (40% fat)	3.6	2.4	0.8	0.7	1.709	0.124	2.364
UHT milk (3.5% fat)	1.0	1.2	0.3	0.4	6.070	1.086	1.261

Table 7 shows the relative difference of the two allocation results. The comparison of the different allocation procedures shows the smallest difference for raw milk input. Yogurt has more raw milk input in the LCA dairy model because of the higher fat content of the yogurt in the LCA dairy model compared to the yogurt in the publication of Feitz et al. In the other process stages, the results of the two allocation types are very different, especially for cream (40% fat).

Table 7: Relative difference between the data of the LCA dairy model and the allocation of the LCA dairy model data as proposed by Feitz et al (2007) for the 3 products yogurt, cream (40%) and UHT milk. Formula used: (input in LCA dairy model – input Feitz)/input Feitz).

Relative change of allocation in our model compared to Feitz et al. (2007)							
	Raw milk	*Water use*	*Elec-tricity*	*Themal energy / Steam use*	*Alkaline cleaners / NaOH 50 %*	*Acid cleaners / HNO3 70 %*	*Waste water*
Yogurt	17%	-29%	-50%	-31%	-70%	-87%	-30%
Cream (40% fat)	3%	76%	357%	207%	-62%	-83%	74%
UHT milk	-7%	-8%	-12%	-15%	35%	46%	-7%

The water, steam and electricity use allocated to cream is much higher in our model than in the model of Feitz. In case of electricity, most of the electricity that is used for cream (40% fat) stems from the additional input modelled in the LCA dairy model. This input is added to the raw milk and the allocation of the milk separation step is conducted according to milk solids, a relatively high amount of this additional input is passed on to the cream (40% fat). In the case of water use and thermal energy (in the LCA dairy model: steam for CIP and for heating), most of the input stems from the separation and pasteurization step of raw milk, that is again passed on mainly to the cream. This could be an explanation why relatively more fuel is needed to produce cream (40% fat) in the LCA dairy model than expected according to the allocation of Feitz et al. Feitz[9] states that they could not differentiate between standard cream and milk and assumed that they need the same amount of inputs. For this aspect, our model is more detailed and could be more accurate.

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[9] Feitz, Andrew. Personal communication via e-mail on 14.4.2016.

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