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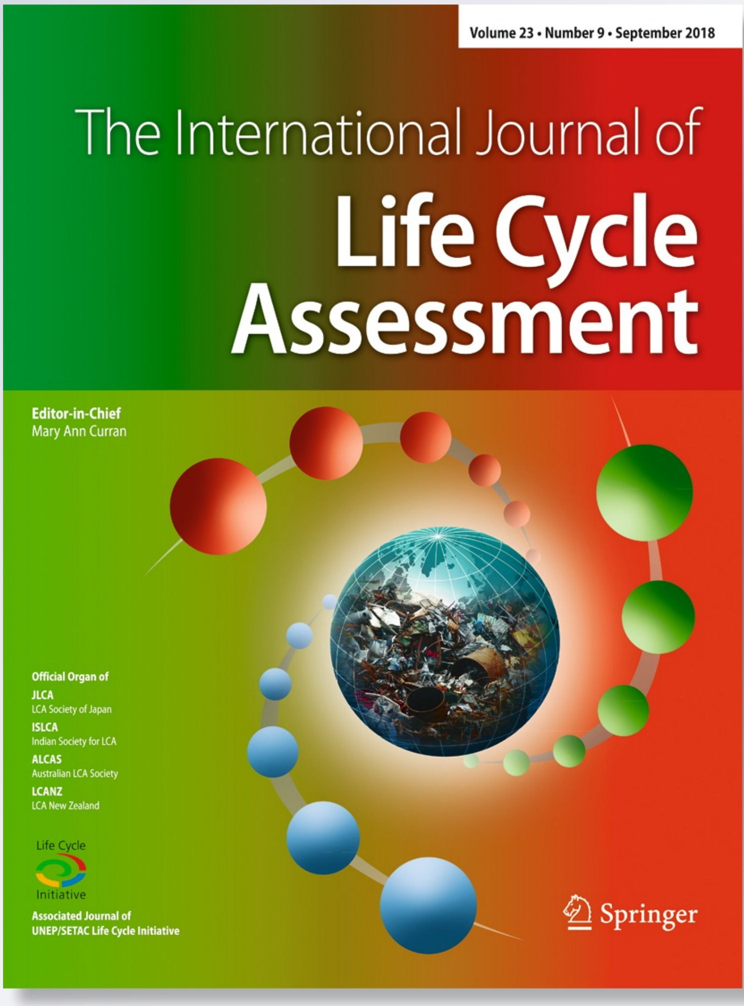

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LCA FOR ENERGY SYSTEMS AND FOOD PRODUCTS

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

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Abstract

Purpose This study analyses the environmental impacts referring to dairy products and to the operation of a dairy. The study aims to better understand different process stages in a dairy operation. This analysis can be used to improve the flows of energy, water, and materials in the dairy operation. The results are also used to suggest an improved allocation model for assigning the impacts of operation to single dairy products.

Methods The analysis is based on a detailed, product-specific model calculation for the use of energy, water, and chemicals for more than 40 subprocesses of a dairy operation. This model has been used to elaborate the life cycle inventory for a detailed life cycle assessment study. The environmental impacts are analyzed from cradle to gate including and excluding the raw milk input. The environmental impacts are assessed with the midpoint indicators suggested by the International Reference Life Cycle Data System. Finally, results of this study are compared with an allocation model recommended for life cycle assessment (LCA) studies on milk products.

Results and discussion 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 detailed dairy processing model allows the assignment of inputs and outputs for each subprocess to single dairy products and thus avoids allocation largely. The analysis of inputs to different dairy products per kilogram shows that ultra-high-temperature (UHT)-processed milk uses more chemicals for cleaning compared to the other products. Cream uses more electricity and heat compared to UHT milk and to yogurt.

Conclusions A detailed discussion shows the overlaps and differences found for the allocation of inputs to the milk processing to final dairy products. Allocation models for different types of inputs are partly confirmed by the detailed theoretical model used for this LCA. The allocation of chemicals, steam, and electricity to single products can be improved based on the detailed dairy model developed in this study.

Keywords Allocation · Carbon footprint · Dairy model · Milk processing · Milk products

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1 Introduction

Dairy manufacturing plants usually produce more than one product because the fat content in raw milk exceeds the product specification for milk powder or fresh milk products (e.g., whole milk or yogurt). The excess milk fat can be further processed into butter or cream (IDF 2015).

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

An important contribution to this problem is the recommendation of the International Dairy Federation (IDF 2010) for an allocation method based on a detailed evaluation of inputs and outputs in different types of dairies (Feitz et al. 2007). Before, allocation on dairy products often has been

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

	Flow name	Packaging	Amount
Raw milk input	Raw milk (4.2% fat)	None	618,387
Dairy products	UHT 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

performed by generic allocation criteria like revenue, mass, or fat content. In 2015, an updated version of these recommendations was published (IDF 2015). Here, an allocation of all inputs and outputs according to the milk solid content is recommended based on another publication (Flysjö et al. 2014).

In the European SUSMILK project (www.susmilk.com), a detailed bottom-up model of a theoretical generic dairy was compiled with the product portfolio given in Table 1 (Maga and Font Brucart 2016; Maga et al. 2014). The model of Maga et al. gives the inputs and outputs for more than 40 production subprocesses in the dairy (i.e., separation, pasteurization) and a detailed modeling of CIP-cleaning (clean in place) for each machinery involved. This model was complemented with additional inputs (i.e., packaging material, infrastructure, and additional water and electricity inputs) to account for all inputs of the dairy operation from cradle to gate and results in the life cycle assessment (LCA) dairy model (Jungbluth et al. 2016a).

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 the basic dairy model and of several improvement options (heat provision, cooling) is described in a detailed life cycle assessment published for this project (Jungbluth et al. 2014; Jungbluth et al. 2016a; Jungbluth et al. 2016b).

For this article, we focus on the achievements made concerning the allocation of processing impacts to single dairy products. This part of the LCA work has been presented during the LCA food conference in 2016 (Jungbluth and Keller 2016). The paper written for the proceedings forms the basis of this article (Keller et al. 2016). The paper was revised, reread, and additional review comments were taken into account.

The allocation of the inputs calculated according to the dairy model is compared in this paper to the allocation method suggested by the International Dairy Federation (IDF 2010), based on (Feitz et al. 2007). This recommendation can be followed if data is only available for a whole dairy company or dairy site. In addition, the differences in results between these two approaches are discussed.

Cheese making with whey as a by-product as the second important allocation question in dairy processing was not investigated in this research work.

2 Methods

2.1 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

Fig. 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

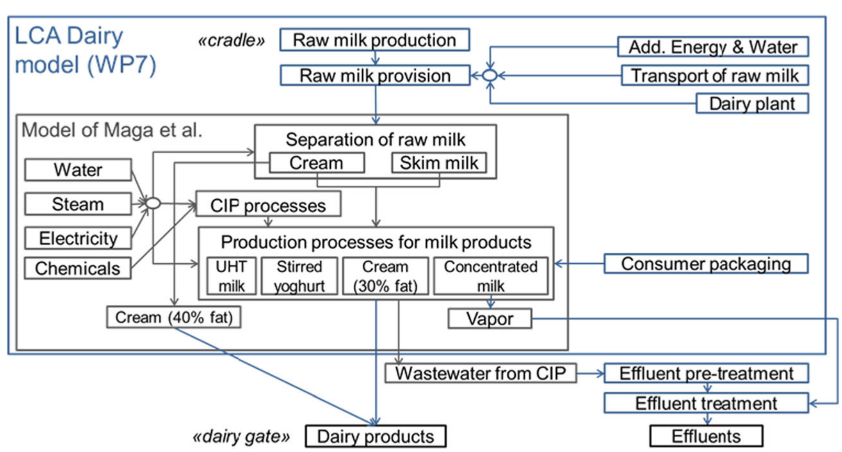

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Table 2 Properties of the products of the model dairy, given in mass percentage

Product	Raw milk	UHT milk	Stirred yogurt	Cream (30% fat)	Concentrated 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

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 a detailed model for processing in the dairy (dairy model) and compare these results to the recommendation of the International Dairy Foundation (IDF 2010).

The scope of the LCA is from cradle to (dairy) gate, including the treatment of waste (i.e. wastewater) up to gate plus post-consumer waste of packaging. System boundaries and a simplified model for the LCA is shown in Fig. 1. 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 1 day of operation modeled in the dairy model (600,000 l raw milk). The functional unit for the analysis of the products is 1 kg of dairy product also at dairy plant gate. This LCA focuses on the analysis of impacts but 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 et al. 2010).

2.2 Life cycle inventory analysis (LCI)

A detailed Excel model for a generic dairy was developed in the SUSMILK project to provide a basis for analysis and optimization. This model provides a detailed picture of a typical European dairy, which produces ultra-high-temperature (UHT) milk (3.5% fat), concentrated milk (0.2% fat), yogurt (10% fat), and cream (30%/40% fat) in regard to the consumption of water and energy. It analyses the production processes, cleaning in place (CIP) systems, and other utilities, where all the required data were collected at the unit process level. The generic dairy was assumed to be located in the chosen baseline city Oberhausen (Germany). The data supplied from the dairy

Table 3 Names 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 modeling in the generic dairy model
Steam for production/CIP[a]	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

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

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Table 4 Inputs per kilogram of product given by the LCA dairy model

	Raw milk (kg)	Water use (kg)	Electricity (MJ)	Steam use (MJ)	NaOH 50% (g)	HNO3 70% (g)	Wastewater (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

project partners, literature research, and data contributed by project partners were the sources used in modeling the generic dairy (Maga and Font Brucart 2016). All internal streams of the processing for single products (see product portfolio and properties in Table 2) as well as of steam (heat provision), cold water (cooling), and electricity are included in the modeling.

This model was used as a base case to:

(1) assess the relative environmental impact of the technologies studied in the SUSMILK project (i.e., absorption chiller, heat pumps, and pellet-solar system);
(2) conduct the life cycle assessment of the whole dairy also considering additional technological options;
(3) carry out the exergy analysis;
(4) provide basic conditions for calculating the payback period of the technologies studied in the SUSMILK project; and
(5) develop a so called green dairy model.

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 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 included in the dataset of the raw milk provision (Jungbluth et al. 2016a). The ecoinvent database v2.2 and available updates, as well as ESU data-on-demand, are used as a background database for the life cycle inventory analysis (ecoinvent Centre 2010; ESU 2017; Jungbluth et al. 2017). The raw milk separation step[1] is allocated with milk solids (given in Table 2) as suggested by the IDF (IDF 2010) and Feitz et al. (2007).

[1] 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.

3 Results

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. It has therefore not been investigated in further detail.

The analysis of the dairy operation excluding the raw milk production[2] shows that the crucial process stage depends on the impact category (see Fig. 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.

In the impact category climate change (see Fig. 3), 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 of aluminum foil and cardboard. The 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.[3] 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"

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

[3] 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.

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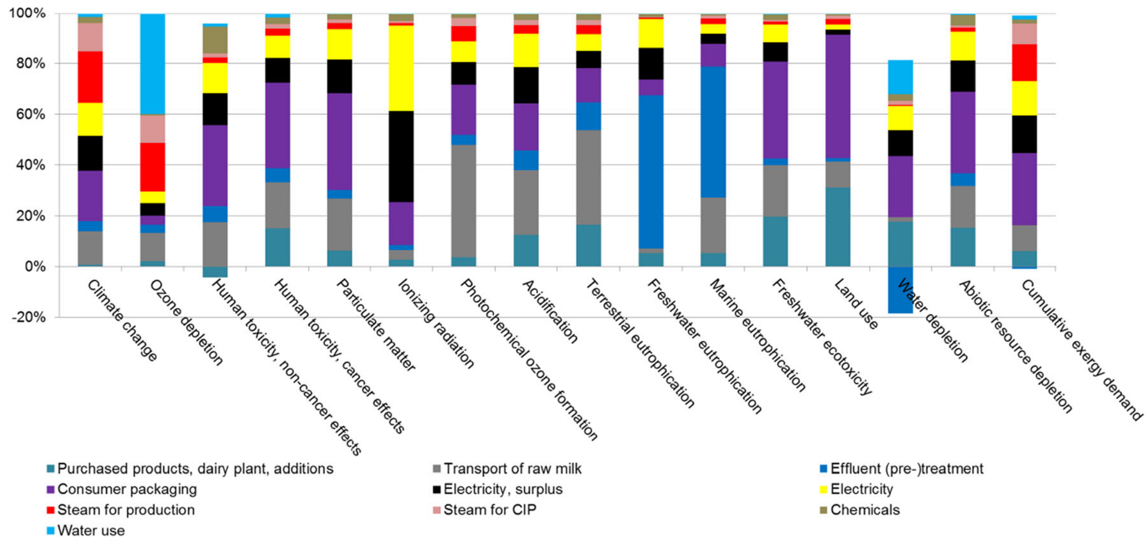

Fig. 2 ILDC impact categories: Analysis of the dairy operation per day without the raw milk production and without allocation to single products. Percentage share of each process stage on the total impact in each category is depicted

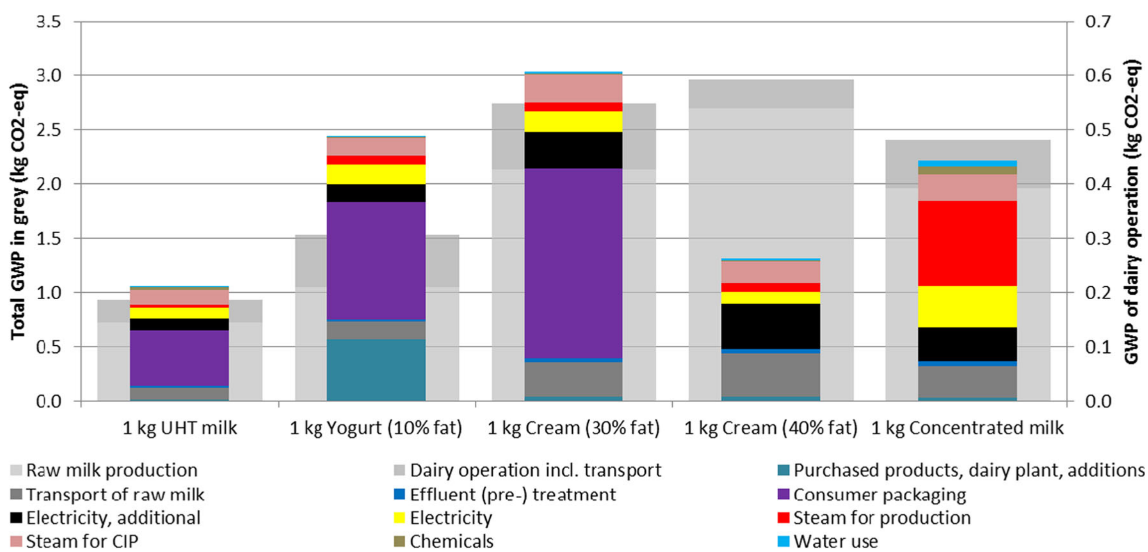

Fig. 3 Comparison of impact on climate change (global warming potential, GWP) of dairy products at dairy gate. Gray columns in the background show the total GWP (cradle to gate), split into raw milk production, and dairy operation (left axis). Colored columns show the subdivision of the dairy operation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

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

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

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

a) Allocation of the generic dairy inputs (three products) according to Feitz et al. (2007)							
	Raw milk (kg)	Water use (kg)	Electricity (MJ)	Thermal energy (MJ)	Alkaline cleaners (g)	Acid cleaners (g)	Wastewater (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	Electricity	Steam use	NaOH 50%	HNO3 70%	Wastewater
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

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.

Also, when referring the impacts on climate change to the different dairy products, raw milk production has by far the biggest share of environmental impact spanning from 70 to 90% (see Fig. 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 wastewater 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%.

4 Discussion

4.1 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 wastewater 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 (purchased) has an important

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 three products yogurt, cream (40%), and UHT milk. Formula used ((input in LCA dairy model—input Feitz)/input Feitz)

	Raw milk	Water use	Electricity	Themal energy/steam use	Alkaline cleaners/NaOH 50%	Acid cleaners/HNO3 70%	Wastewater
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%

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share even though the respective input is less than 2% of the total yogurt weight.[4]

4.2 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. 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).

Results from this approach are compared here with results gained by the modeling with the generic dairy model. The LCI modeling with the generic dairy model does not need any allocation besides the allocation in the first stage "separation of raw milk," which is based on the content of milk solids in raw milk and the two intermediate products. All following subprocesses have only one product output. A cut-off was applied to waste heat streams from subprocesses going back for reheating or reuse. Thus, the subdivision of the dairy processing allows avoiding an overall allocation between all inputs and outputs of the dairy.

It has to be noted that product properties (e.g., fat content) can vary considerable and thus results are not exactly comparable.

Table 5 first shows the input per kilogram of market milk according to the model dairy used in the publication of Feitz et al. (2007) (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. (2007) is shown (UHT milk in Table 5b and all three products in Table 6b).

The inputs per kilogram of market milk in the model dairy of Feitz et al. (2007) (Table 5a) are similar to the inputs of UHT milk in the LCA dairy model (Table 5b). An exception is the input of alkaline cleaners. There, a much higher amount is modeled according to the LCA dairy model compared to Feitz et al. (2007).

Table 6 shows the allocation of Feitz et al. (2007) (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. (2007), but also the share allocated to UHT milk is higher. In Feitz et al. (2007), the same share is suggested for these products. According to Feitz et al. (2007), the resolution in their study was not high enough to identify, i.e., different cleaning figures for UHT milk and for fresh milk.[5] The values used in the LCA dairy model are more specific to these 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.

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. (2007). In the other process stages, the results of the two allocation types are very different, especially for cream (40% fat).

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 modeled 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. (2007). Feitz[6] states that they could not differentiate between standard cream and milk and assumed that they need the same amount of inputs. Thus, regarding this aspect, our model with an allocation based on allocation in the raw milk separation is more detailed than the model of Feitz who did not differentiate for this stage.

The evaluation in Fig. 3 shows that impacts of raw milk provision, and processing impacts are not linear connected.

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

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

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

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This emphasizes that a detailed allocation for the impacts of dairy processing might be closer to reality than a simple allocation by dry matter content as proposed in the present recommendations of the IDF (IDF 2015).

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References

ecoinvent Centre (2010) ecoinvent data v2.2, ecoinvent reports No. 1–25. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

ESU (2017) The ESU database 2017. ESU-services Ltd., Schaffhausen

European Commission, Joint Research Centre, Institute for Environment and Sustainability (2010) International reference life cycle data system (ILCD) handbook—specific guide for life cycle inventory data sets. Publication office of the European Union, Luxembourg

Feitz AJ, Lundie S, Dennien G, Morain M, Jones M (2007) Generation of an industry-specific physico-chemical allocation matrix. Application in the dairy industry and implications for system analysis. Int J LCA 12:109–117

Flysjö A, Thrane M, Hermansen JE (2014) Method to assess the carbon footprint at product level in the dairy industry. Int Dairy J 34:86–92. https://doi.org/10.1016/j.idairyj.2013.07.016

IDF (2010) A common carbon footprint approach for dairy. The IDF guide to standard lifecycle assessment methodology for the dairy sector. Bulletin of the International Dairy Federation 445/2010

IDF (2015) A common carbon footprint approach for dairy. The IDF guide to standard lifecycle assessment methodology for the dairy sector. Bulletin of the International Dairy Federation 479/2015

Jungbluth N, Keller R (2016) Milk processing—life cycle assessment of a detailed dairy model and recommendations for the allocation to single products (presentation slides). In: Holden N (ed) The 10th International Conference on Life Cycle Assessment of Food (LCA Food 2016), Dublin, Irland, 19th – 21st October 2016. University College Dublin (UCD)

Jungbluth N, Keller R, Doublet G (2014) Goal and scope definition for the life cycle assessment vol Deliverable 7.1. SUSMILK - Re-design of the dairy industry for sustainable milk processing. Project funded by the European Commission within the 7th Framework Programme. Project number n°613589. ESU-services Ltd., Zurich

Jungbluth N, Keller R, Doublet G, König A, Eggenberger S (2016a) Report on life cycle assessment, economic assessment, potential employment effects and exergy-based analysis: part I—LCA vol Deliverable 7.3. SUSMILK: Re-design of the dairy industry for sustainable milk processing. Project funded by the European Commission within the 7th Framework Programme. Project number n°613589

Jungbluth N, Keller R, König A, Eggenberger S (2016b) Life cycle inventory analysis vol Deliverable D7.2. (confidential) SUSMILK: Re-design of the dairy industry for sustainable milk processing. Project funded by the European Commission within the 7th Framework Programme. Project number n°613589. ESU-services Ltd.

Jungbluth N, Meili C, Keller R, Eggenberger S, König A, Doublet G, Flury K, Büsser S, Stucki M, Schori S, Itten R, Leuenberger M, Steiner R (2017) Life cycle inventory database on demand: EcoSpold LCI database of ESU-services. ESU-services Ltd., Schaffhausen retrieved from: www.esuservices.ch/data/data-on-demand/

Keller R, Jungbluth N, Eggenberger S (2016) Milk processing—life cycle assessment of a detailed dairy model and recommendations for the allocation to single products (paper). In: Holden N (ed) The 10th International Conference on Life Cycle Assessment of Food (LCA Food 2016), Dublin, Irland, 19th – 21st October 2016. University College Dublin (UCD)

Maga D, Font Brucart M (2016) Report on data assessment and material and energy balances vol Deliverable 1.2. SUSMILK - Re-design of the dairy industry for sustainable milk processing. Project funded by the European Commission within the 7th Framework Programme. Project number n°613589. Fraunhofer UMSICHT, Oberhausen

Maga D, Font Brucat M, Glasner C (2014) Report on dairy technology vol Deliverable 1.1. SUSMILK - Re-design of the dairy industry for sustainable milk processing. Project funded by the European Commission within the 7th Framework Programme. Project number n°613589. Fraunhofer UMSICHT, Oberhausen