Product Chain Actors' Potential for Greening the Product Life Cycle

The Case of the Swedish Postfarm Milk Chain

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Summary

The challenge in working with environmental improvements is to select the action offering the most substantial progress. However, not all actions are open to all actors in a product chain. This study demonstrates how life cycle assessment (LCA) may be used with an actor perspective in the Swedish postfarm milk chain. The potential measures were identified, applied by the dairy, retailer, and household, that gave the most environmental improvement in a life cycle perspective. Improved energy efficiency, more efficient transport patterns, reduced milk and product losses, and organic labeling were investigated. Milk, yogurt and cheese were considered. After LCAs of the products were established, improvement potentials of the actors were identified and quantified. The quantification was based mostly on literature studies but also on assumptions. Then the LCAs were recalculated to include the estimated improvement potential. To find the action with the greatest potential, the environmental impacts of the modified and original LCAs were compared for each actor. No action was superior to any other from the dairy perspective, but reduced wastage lowered most impacts for all three products. For retailers, using less energy is the most efficient improvement. From the household perspective, reducing wastage gives unambiguously positive results. When households choose organic products, reductions in energy use and greenhouse gases are even larger, but eutrophication increases. Overall, households have greatest potential for improvement while yogurt is the product offering the most improvement potential.

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Introduction

The growing awareness of environmental issues in society has led to actions to decrease unwanted environmental consequences and could do so to an even greater extent. Actions may be taken on all levels, including societal, industrial, and individual. Policy instruments, technical developments, and consumption behavior affect the environment significantly. The challenge is not only to select the action that makes the most substantial improvements but also to identify which one may be taken by which actor. This challenge was expressed by Andrews (2000) to move research within industrial ecology beyond "what" to "how" questions with an explicit consideration of actors. "How" reflects measures available to actors for solving their environmental problems.

Within the food sector, measures to decrease environmental impact are continuously applied. Examples include improved plant nutrient balances on farms, decreased use of packaging, better logistic solutions, more energy-efficient processes, and environmental requirements for procurement. Action for environmental improvement is traditionally taken at each part of the food chain (Berlin 2005). Several life cycle assessments (LCAs) of various food products have identified farming as the dominant contributor to the environmental impacts (e.g., Andersson and Ohlsson 1999; Berlin 2002; Högaas Eide 2002; Jungbluth et al. 2000; Weidema et al. 1995). For example, the LCA of semihard cheese by Berlin (2002) showed that, on a life cycle basis, the agriculture phase contributed 94% to global warming, 99% to acidification, and 99% to eutrophication. Consequently, environmental improvement within the agricultural phase is important. Swedish dairy farming has been thoroughly investigated with systems analysis methodology and for environmental improvement purposes by Cederberg (2002), Elmquist (2005), and Mattsson (1999). Another example from the Spanish dairy sector is a study by Hospido and colleagues (2003) that identified and quantified three actions within agriculture to achieve substantial environmental improvements. These were reduction of milk losses during milking, a changed feed composition with more maize and less silage, and implementation of treatment systems for water and air emissions.

Quantified assessments of improvement potentials in the life cycle stages following agriculture are, however, rare in LCAs of food products and, in particular, of dairy products. Högaas Eide (2002) offered nine alternative ways to reduce the environmental impact from the life cycle of milk, but these were not ranked quantitatively. Cheese was investigated by Berlin (2002), and improvement actions were suggested, but no quantitative assessment of them was made in that study, either. Nevertheless, Jungbluth and colleagues (2000) identified the consumer as the actor in the food chain who has the widest range of options to "green" the life cycles of meat and vegetables. Five separate kinds of decisions were compared: type of agricultural practice, origin, packaging material, type of preservation, and consumption. The most important options for a reduction of environmental impact turned out to be refusal of air-transported products, a preference for organic products, and a reduction in meat consumption. We think, however, that the environmental actions of all the actors in the food chain can be of importance and should be investigated. In accordance with the study by Jungbluth and colleagues (2000), the environmental consequences of the actions should be assessed in a life cycle perspective. The research reported here is a case study in which potential improvement actions of actors in the food chain are assessed in a life cycle perspective. The study excludes the already well-researched agricultural step, which implies that no potential improvements in agriculture were considered. Nevertheless, improvement potentials of other actors in the food chain are investigated, including their consequences for the agricultural step.

The aim of this study is twofold. The first aim is to demonstrate how LCA may be used together with an actor perspective to evaluate the life cycle implications of potential improvement actions of individual actors in the milk chain. The second aim is to present concrete results from the case of the Swedish postfarm milk chain. The overall objective of the case study is to identify what potential actions, undertaken by the different actors in the postfarm milk chain, lead to the greatest life cycle improvements. The specific objective is to compare the actions by quantifying environmental impacts of the milk chain. Implementing the measures studied should be possible within a timeframe of 5 years. The improvements studied would not require advanced technical equipment changes or major investments. Only potential measures taken by participants in the postfarm milk chain are investigated; the consequences of policy are excluded. The actors in the postfarm milk chain are the focus of this case study.

Trends in the Dairy Sector

The potential actions to decrease the environmental impact that can be undertaken by the different actors in the postfarm chain are related to trends of the dairy sector. A survey of the current trends and developments of the chain and their environmental consequences shows that there is a tendency in the dairy industry toward production in a few large, specialized dairies (Swedish Dairy Association 2005). This implies an energy-efficient industrial production with low energy consumption per unit produced. The existence of fewer dairies, however, leads to longer transports from the dairy to the retailer. Fewer dairies and the dairy farmers' similar movement toward larger but fewer farms also mean longer transport distances from the farm to the dairy. For the retail sector in Sweden, the establishment of supermarkets outside the cities is continuing to increase, which implies longer transportation distances for the customers to reach the supermarkets. These trends suggest both energy consumption and transportation patterns as areas of environmental improvement potential.

Another current trend involving not only the dairies but also the consumers is the rise in diversity of products. Berlin and colleagues (2007) found that the utilization of the resource (milk) during processing was affected by the product diversity. Consumers may generate more waste as they buy a wider variety of products in smaller packages. With a broader spectrum of products in the refrigerator, more of them may be wasted because they are not used in time. Waste also occurs because some product is always left in the container (Johansson 2002) and also because smaller containers lead to rising packaging waste. The risk of increased waste of milk, in both dairies and households, makes milk losses an issue with environmental improvement potential.

Consumer purchases of ecologically labeled products are rising. Organic agriculture, which is supported by governmental decisions within the EU, has consequences for the environmental impact at the farms that differ from those of conventional production.

Method

The study was based on the combination of two methodological approaches. The first of these consists of the identification and, later, quantification of the potential of the actors in the postfarm milk chain to improve the life cycle environmental performance of the milk chain. The question we asked ourselves in this phase of the project was not so much "How may the industry (or the retailers or the consumers) be influenced to improve environmentally?" Rather, it was "What can they do? What actions are in their power?" These potential actions were then evaluated with LCA methodology and LCA data from existing studies. We now describe how these two methodological elements were applied, first conceptually and then in more detail, including the quantification of improvement potentials and the data sources for the LCA. Finally, we describe how the two approaches were combined in a quantitative manner.

Potential Improvement Actions: Identification and Quantification

The potential improvement actions were first identified in a brainstorming session with the researchers involved in this project, which utilized their understanding of life cycle thinking and LCA methodology, combined with their experience in LCA studies of dairy products. First, the postfarm milk chain was divided into the main actors: the dairy industry, the retailers, and the consumers. Their potential actions to green the milk chain were then listed. Although the same actions were not identified for all actors, they could be sorted under the main strategies of improved energy efficiency, changed transport patterns, reduction of product losses, and use of ecological labeling. The same strategies were highlighted as areas with environmental improvement potential through an analysis of the trends in the dairy sector. It needs to be pointed out that although most of these strategies are relevant for all actors, they do not imply the same action for the different actors. For instance, reduction of product losses means for the dairy that management seeks production and process solutions to reduce raw material and product losses, whereas for the retailers it implies reduction of unsold products, and for the households it entails an improved planning of purchasing and meals. We chose to limit the study to actions that would not influence the product composition or the package.

The potential for the actors to improve in any of the four aspects—namely, energy efficiency, transportation, product losses, and use of ecological labeling—was then quantified through literature studies and estimations. A conservative quantification was made, which means that the environmental benefits of the improvement actions were underestimated rather than exaggerated. In the case of dairies, the estimated values were verified through interviews with the processing managers of three Swedish dairies. The data collected for the other actors hold a larger uncertainty, as no such verification was possible. Even so, we determined that the trends and ranking orders (which actions matter and which do not, which actors in the milk chain hold a smaller or larger potential for environmental improvement) should still be valid, as should the actor perspective of the analysis. The quantified improvement potentials are given in the Results section.

LCA of Dairy Products

Dairy products make up the largest part of the Swedish diet, constituting 25% by mass of the total food intake in Sweden (SEPA 1999). The Swedish National Food Administration recommends a daily intake of 0.5 L of milk or a corresponding amount of other dairy products. That is why dairy products were chosen for this study. Three dairy products—milk, yogurt, and cheese—were selected for the assessment. They were chosen as they represent the most important categories of consumed dairy products in Sweden. Although all three products are categorized as fresh, there are differences in processing, number of flavors, shelf life, and consistency, which generate different impacts on the environment. The products are assumed to be produced, purchased, and consumed in Sweden. This implies that all data used along the milk chain are Swedish, with just one exception.

The environmental impact studies of the three products were carried out with LCA methodology (Baumann and Tillman 2004; ISO 2006a, 2006b). The starting point was previously published life cycle inventories and LCAs of these products (Berlin 2002; Cederberg and Flysjö 2004; Glende 1997). We used data from these studies to construct new inventories, applying the following system boundaries: The products' life cycles started at the agriculture phase and ended with a consumed product in the household or a waste of product at the sewage treatment plant (figure 1).

The data used for the agricultural phase and its inputs included animal husbandry with all raw materials, such as production of fertilizers, diesel,

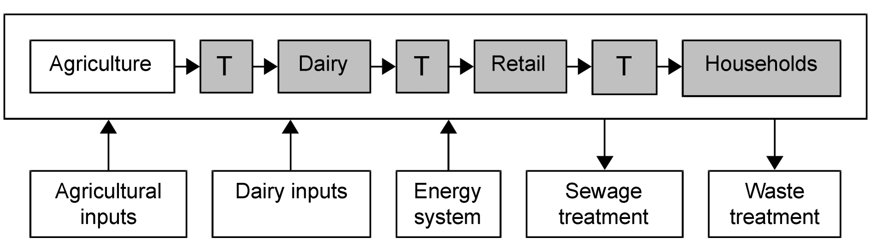

Figure 1 The system boundaries applied for the life cycle assessment calculations. The shaded boxes represent activities for which life cycle consequences of improvement actions were analyzed. T = transportation.

pesticides, and seeds; cultivation of oil/starch crops and sugar beets; processing at the feed industry; and all transports (Cederberg and Flysjö 2004). The dairy data used included the activities of a general milk treatment followed by specific product treatment for each of the three products (Berlin 2002; Glende 1997). In the handbook by Bylund (1995), dairy processing is thoroughly explained. The dairy input data included production of drinking water, raw material acquisition, and processing of detergents as well as life cycle data on packaging production (Berlin et al. 2007). Data used for the retailer activity as well as the household activity were limited to cold storage, as it is the only process with environmental consequences for these stages. Extraction of energy sources, production, and refining of energy sources as well as combustion or production of electricity were included in the data for energy systems. Data on sewage treatment included the treatment of the dairy sewage. The waste management included the processes of incineration of packaging waste, which is the Swedish waste management practice besides recycling. Neither production nor maintenance of capital goods was included in this study. The functional unit was 1 kg of consumed dairy product in the household.

The environmental impact was calculated according to LCA methodology (Baumann and Tillman 2004; ISO 2006a, 2006b). The environmental impact categories considered were eutrophication, global warming (100 years), and photochemical ozone creation potential (POCP). The categories specified included the key parameters for the environmental impact of food production identified by Mattsson (1999). The key inventory parameters were nitrous oxide, methane, ammonia, and energy-related emissions. The sources for the equivalence factors were work by Lindfors and colleagues (1995) for eutrophication; Houghton and colleagues (1990), SEPA (1992), and IPCC (1995) for global warming 100 years; and Heijungs and colleagues (1992) and Andersson-Sköld and colleagues (1992) for POCP. The impact of the energy requirements of the product life cycles were included in these impact categories, as the emissions released during the extraction, production, and use of energy contributed to the impact categories. To increase our understanding of the use of energy, however, we reported the amount of secondary energy required as well.

The Swedish electricity mix was used in this study. For a consequential study such as this, it would have been preferable to use marginal electricity data. This was not possible, as the data sources for the study were previously published life cycle inventories and LCAs in which the average electricity mix was used. Conversely, the choice of average energy mix is a conservative one (i.e., the environmental benefits of the improvement actions were underestimated rather than exaggerated), which makes the results less prone to criticism and easier to communicate.

Combination of Quantified Improvement Actions and LCA

Each improvement action sorted under the identified strategies (improved energy efficiency, changed transport patterns, reduction of product losses, and use of ecological labeling) was identified for each actor. The improvement potentials were then quantified in relation to current practice. For some actors there were several improvement actions possible within each strategy. In these cases, we combined all the quantified improvements to get a total improvement potential for that actor within the strategy. The actions and data sources are described below and summarized in table 1.

To get a reference environmental load, we compiled LCAs for the three products: drinking milk, yogurt, and cheese (as detailed above). Thereafter, we recalculated the LCAs, taking into account the quantified improvement actions for each of the products and each of the strategies. Then we compared the environmental impact of the modified LCAs and the original ones for each actor. This made it possible to identify the most efficient action for the dairy, the retailer, and the household, respectively. No combinations of actions of several actors were tested, but the actors were studied one at a time.

Data and Data Sources

In this section the estimated improvement potentials are presented, followed by a summary

Table 1 The improvement potential of actions that can be taken by the postfarm actors

	Energy efficiency		*Transport patterns*		*Product losses*		
Phase	*Product*	%	*Product*	%	*Product*	%	*Organic labeling*
Dairy	*Processing*		*Eco-driving*		*Milk treatment*		–
	Milk	5	Milk	10	Milk	15	
	Cheese	6	Cheese	10	Cheese	15	
	Yogurt	8	Yogurt	10	Yogurt	15	
			Local distribution		*Product Processing*		
			Milk	12	Milk	–	
			Cheese	12	Cheese	2.5	
			Yogurt	12	Yogurt	12 + 12	
Retailer	*Cold storage*				*Unsold products*		
	Milk	50			Milk	50	
	Cheese	50			Cheese	0	
	Yogurt	50			Yogurt	50	
Household	*Cold storage*		*Eco-driving*		*Losses in drainage*		*Organic products*
	Milk	42	Milk	10	Milk	50	Milk*
	Cheese	42	Cheese	10	Cheese	5	Cheese*
	Yogurt	42	Yogurt	10	Yogurt	50	Yogurt*
			Fuel use/km		*Losses in packaging*		
			Milk	12	Milk	0	
			Cheese	12	Cheese	0	
			Yogurt	12	Yogurt	2.55	
			Frequency food shopping				
			Milk	31			
			Cheese	31			
			Yogurt	31			

Note: The actions are listed for the three products under study: milk, cheese, and yogurt. The improvement potentials are given in percentages of the consequences of the specific action compared to current practice.
*All consumer purchases of milk, cheese, and yogurt have changed from conventionally produced products to organically produced.

table. Then the data sources for the LCA and some of the actual data are presented.

Identification of Actions and Their Improvement Potential

The postfarm actors' improvement potentials of four possible courses of action were quantified.

Dairy

At the dairy, the energy efficiency potential is linked to the product itself. Milk is processed less than yogurt, whereas cheese requires the most processing of the three. The energy improvement potential used for milk production was estimated to be 5%, which is the goal for energy savings at the largest dairy company in Sweden (Karlsson et al. 2004). For production of cultured products, yogurt included, a study was made to identify ways to enhance the energy efficiency (Karlsson et al. 2004). The total improvement potential was found to be 8%, which was used in this study. During cheese-making, a reasonable improvement potential of energy savings would be 6%, according to the manager of the largest cheese-making dairy in Sweden (Nilsson 2005).

The dairies' main transports are from the farm to the dairy and from the dairy to the retailer (regional and local distribution). A reduction of 10% was judged to be possible for all transports through improved driving technique (eco-driving). If it were possible to change from one shift to two shifts for the local distribution drivers (the last part of the delivery to the retailer), this would facilitate getting rid of 16% of the oldest trucks, according to the manager of logistics at Arla Foods (Carlson 2005)—that is, those trucks that have the most impact on the environment. The older trucks taken out of operation would be those driving on Euro 0 diesel fuel, whereas those retained in operation would be those driving on Euro 3 diesel (i.e., lower emissions of nitrogen oxides, hydrocarbons, and carbon monoxide than Euro 0 diesel; Volvo Trucks 2006). The result was that 12% improvement would be enabled by this change of vehicles in the local distribution. The calculation was based on the Swedish legal requirement for Euro 3 diesel and Euro 0 diesel. The improvement potential was obtained by the average difference of allowed nitrogen oxides, hydrocarbons, and carbon monoxide emissions for the better Euro 3 diesel compared to Euro 0 diesel and the number of trucks that could be taken out of operation. The change from one to two shifts would, however, affect the retailer, who would have to accept deliveries in the afternoon. At present, the delivery takes place between 6 A.M. and 2 P.M.

For drinking milk production, the processing manager of a large dairy estimated an improvement potential of 15% for lowering milk waste (Polvi 2005). The same data have been used for the milk treatment part of both yogurt processing and cheese-making. For the actual yogurt processing (pasteurization, fermentation, packaging), the waste could be assumed to be decreased by 12%, according to the processing manager of a yogurt-producing dairy (Gleisner 2005). By sequencing yogurt products with the goal of waste minimization, Berlin and Sonesson (2008) found a possible yogurt loss reduction of 29%. Nevertheless, as constructing the sequence from an environmental standpoint is rare in the dairy industry of today and given that the future perspective in this study is 5 years, the assumption of a 12% decrease was used. For the cheese-making process, the potential reduction of losses was estimated to be 2.5% by the manager of the largest cheese-making dairy in Sweden (Nilsson 2005).

Retailer

At the retailer level, a 50% reduction of the energy consumption of the refrigerators would be possible, according to Axell (2002). Unsold products at the retailers constitute a small part of the total losses over the life cycle. Nevertheless, it was assumed that losses from unsold products could be reduced by 50% for milk and yogurt. Cheese can be stored for a long time; therefore, no losses at the retailer were assumed.

Household

The possible energy reduction of refrigerator consumption at the household was 42%. This value was based on the difference between the average energy consumption of 119 units and the lowest level of consumption (Sonesson et al. 2003). The data originated from tests of refrigerators at the Swedish market.

The home transports can be improved in two ways besides eco-driving (10% improvement): using cars with lower gasoline consumption, and decreasing the frequency of food purchases. We assumed a 12% reduction in the gasoline requirement of the car. The figure was based on a comparison between the gasoline requirement of the cars used in Sweden today and the gasoline requirements of newer cars. The consumer's transport between retailer and household was based on a survey of Swedish households (Sonesson et al. 2005). According to that survey, the frequency of food purchasing is 2.9 times a week. This figure includes an allocation of transports that combines food purchase with other transport-requiring activities. We assumed that food shopping could be reduced to twice a week without affecting consumers' way of planning food purchases to a large extent, which lowered distance traveled by 31%.

Substantial losses of products take place in households. Losses may be reduced if consumer behavior is changed and if the packaging design or material is changed. Milk has a short shelf life (7 days) and therefore sometimes ends up down the drain. Yogurt has a shelf life of 28 days, but it is not always consumed. No data were available in the literature regarding losses of milk and yogurt in households. To make an estimate, we asked 16 households to quantify their amount of waste. The average loss of milk was 4%, and the loss of yogurt was 10%. It was then assumed that it was possible to reduce these losses by 50%. The same reduction potential was used for cheese. The initial loss of cheese in the household was assumed to be 3% (Berlin 2002).

Of the three products, only for yogurt do significant losses depend on the packaging design. This is due to the thickness of yogurt and its tendency to stick to the packaging surface. To get an estimate of the consumer behavior potential for reduction of losses, we made a limited study to compare three ways of emptying a yogurt package. The "careful consumer" was assumed to open the top of the package and squeeze out the yogurt. The "patient consumer" puts the package upside down for 5 min, and, finally, the "lazy consumer" just pours the product out of the package until it seems as if the package is empty and squeezes just enough to stop the dripping. The careful consumer lost 3.4%, the patient one lost 6.8%, and the lazy one lost 8.5%. The result for the lazy consumer was similar to that in a study by Johansson (2002). She came to the conclusion that when the consumer thought the package was empty, it still contained 8.6% of the product. The difference between the careful and the lazy consumers of our study divided by 2 was used as a potential reduction of losses that can be influenced by consumer behavior.

If consumers decide to purchase products with organic labels, this will change the environmental impact from the milk chain. The labeling we considered was the Swedish system, KRAV, for organic production (KRAV 2005). KRAV fulfils the requirements of the EU regulation for organic production (EEG 2092/91 1991). Cederberg and Flysjö (2004) have collected data from six organic farms that follow KRAV's regulations. Average values from these farms were used in this study.

Life Cycle Inventory

As some parts of the life cycle are similar for the three products, the same environmental data were used for these parts. These data are described first, followed by specific data for the life cycles of milk, cheese, and yogurt.

Data Used for All Three Products

For the first part, the dairy farm, data from a life cycle inventory of farms in southwestern Sweden were used (Cederberg and Flysjö 2004). Average values of Cederberg and Flysjö's data, collected for 17 conventional farms, were calculated for this study. The milk is picked up at the farm and transported to the dairy; for this transportation, data from Arla Foods were used (Arla Foods 2004). At the retailer, the dairy products must be kept cold. An average value from three retailers of the energy requirement for storing cold products was used, 496 kWh/m^2 per year[2] (Carlson and Sonesson 2000). The area required for the products was measured, and the number of days the products are stored at the retailer was estimated.

Consumers purchasing the products use various modes of transportation—walking, biking, public transportation, and car transportation. Only car transportation (which was used in 59% of the consumer purchasing transports) has been considered to influence the environmental impact. The average distance traveled by car for food purchasing for 45,000 Swedish inhabitants was 7.81 km (Orremo et al. 1999), with an assumed gasoline requirement of 0.1 L/km.

We calculated economic allocation between the dairy products under study and other products purchased at the same time (Orremo et al. 1999). The prices at the retailer were as follows: for milk, 8.50 Swedish kronor (SEK[3]) per liter; for yogurt, SEK 18 per liter; and for cheese, SEK 60 per kilogram. The dairy product, when it has finally reached the household, must be kept cold. The energy requirement was calculated on the basis of the average refrigerator's electricity consumption (0.017 MJ per liter and day; Weidema et al. 1995), the space required for the product under study in the refrigerator, the Swedish consumption of the product under study (Swedish Board of Agriculture 2000), and an average of 2.2 persons in the same household (SCB 2000). The Swedish mix of energy sources used for electricity production was used; this consists mainly of nuclear and hydro power (Swedish Energy Agency 2004).

The Milk Study

The environmental impact caused by drinking milk has been studied with LCA methodology by the Swedish Dairy Association. The data connected with the dairy production, as well as the packaging manufacturing, have been collected from that study (Anonymous 2002; Swedish Dairy Association 2001). For calculation of the energy consumption at the retailer, the time period was assumed to be 1 day, and the measured shelf space was 0.008 m^2. The space required in the refrigerator at the household was assumed to be 3 L.

The Cheese Study

An LCA of semihard cheese has been published by Berlin (2002). In the current study we have used the data collected in Berlin's study together with some updates. The data for the agricultural part were updated with the inventory by Cederberg and Flysjö (2004), as was done for milk and yogurt. The transportation from the farm to the dairy was also the same as for the other products. However, the transportation from the dairy to the retailer was extended 500 km, as nowadays most of the cheese produced in Sweden is stored at the same location. In Berlin's study the storage took place at the cheese-making dairy.

The Yogurt Study

Yogurt production at dairies has been studied at three Norwegian dairies with LCA methodology (Glende 1997). In our study, we used an average value for the energy requirements of the three dairies, but with the Swedish electricity mix. A characteristic of the conventional alkaline and acidic cleaning, which is the most commonly used technique in dairy production, was found in an article by Högaas Eide and colleagues (2003). Sources for life cycle data of water treatment and detergents (nitric acid and sodium hydroxide) were the same as those Berlin and colleagues (2007) used in their model of the environmental impact of product sequencing in production. The same data were used for the manufacturing of the yogurt package as those used for the milk package, but with an adjustment for the packaging weight (Anonymous 2002; Swedish Dairy Association 2001). At the retailer, the yogurt product was estimated to remain for 3 days and require an area of 0.0064 m^2. The refrigerator volume needed for the yogurt in households was assumed to be 3 L.

Results

The quantified results from the study are presented as the total life cycle environmental impact for milk, cheese, and yogurt, separately. The results in table 2 are given per actor (dairy, retail, and household) and type of undertaken improvement measures together with figures of the life cycle environmental impact of the reference situation (i.e., today's system).

The dairy could improve its energy use and transport system while also decreasing the wastage. No action stood out as superior to other actions. Of the three product types, the greatest improvement potential was for yogurt, for which all three actions led to less global warming and energy use; decreased waste also diminished the eutrophication. The largest relative improvements were energy saving (in the use of energy category) and transport efficiency (in the POCP category). For drinking milk, improving transportation seemed to be the most efficient action. For cheese, actions that reduced wastage improved all impact categories, whereas greater energy efficiency was visible only as decreased use of energy, not as reductions of the other impact categories.

The improvement potentials in the retail sector had a very limited effect on the life cycle environmental impact of dairy products. The retailer could reduce its own waste and energy use. Only by decreasing its energy use could the retailer make improvements large enough to show in a total life cycle perspective; the only impact category affected was energy use. Through the adoption of more energy-efficient refrigerators, the total life cycle energy use could be decreased by 1%.

The households could take many measures to reduce the life cycle impact of dairy products. Waste minimization by the consumer clearly led to significant environmental improvement, as all impact categories were reduced in this instance. Hence, the actions of households offered the largest improvement potential, although there was also a risk of increasing some impact categories (see figure 2).

Choosing organic products had a major effect on all three products with regard to energy use and global warming. However, choosing organic milk raised the eutrophication greatly, by more than 20%. The reason for the high contribution to the impact of eutrophication for organic milk products, a result also reported by Cederberg and Mattsson (2000), is the high nitrate loss per produced kilogram of milk at an organic farm. This

Table 2 The life cycle environmental impact of 1 kg of consumed milk, yogurt, and cheese with improvement measures taken by the dairy, retailer, and household separately

Actor of measures	*Product*	*Environmental impact of life cycle*	*Reference*	*Energy savings*	*Transport efficiency*	*Waste reduction*	*Organic labelling*
Dairy	Milk	GWP (g CO_2 eq.)	1 140	1 140	1 130	1 140	–
		Energy use (MJ)	5.8	5.8	5.7	5.8	–
		EP (g O_2 eq.)	206	206	205	205	
		POCP (g ethene eq.)	0.40	0.40	0.40	0.40	–
	Cheese	GWP (g CO_2 eq.)	10 700	10 700	10 700	10 600	–
		Energy use (MJ)	40	40	40	40	–
		EP (g O_2 eq.)	1 980	1 980	1 980	1 960	–
		POCP (g ethene eq.)	3.1	3.1	3.0	3.0	–
	Yogurt	GWP (g CO_2 eq.)	1 450	1 440	1 440	1 440	–
		Energy use (MJ)	8.9	8.7	8.8	8.8	–
		EP (g O_2 eq.)	245	245	244	243	–
		POCP (g ethene eq.)	0.50	0.50	0.49	0.50	–
Retailer	Milk	GWP (g CO_2 eq.)	1 140	1 140	–	1 140	–
		Energy use (MJ)	5.8	5.8	–	5.8	–
		EP (g O_2 eq.)	206	206	–	205	–
		POCP (g ethene eq.)	0.40	0.40	–	0.40	–
	Cheese	GWP (g CO_2 eq.)	10 700	10 700	–	–	–
		Energy use (MJ)	40	39	–	–	–
		EP (g O_2 eq.)	1 980	1 980	–	–	–
		POCP (g ethene eq.)	3.1	3.1	–	–	–
	Yogurt	GWP (g CO_2 eq.)	1 450	1 450	–	1 450	–
		Energy use (MJ)	8.9	8.8	–	8.9	–
		EP (g O_2 eq.)	245	245	–	245	–
		POCP (g ethene eq.)	0.50	0.50	–	0.50	–
Household	Milk	GWP (g CO_2 eq.)	1 140	1 140	1 140	1 120	1 110
		Energy use (MJ)	5.8	5.7	5.8	5.7	5.3
		EP (g O_2 eq.)	206	206	206	202	250
		POCP (g ethene eq.)	0.40	0.40	0.40	0.40	0.41
	Cheese	GWP (g CO_2 eq.)	10 700	10 700	10 700	10 500	10 400
		Energy use (MJ)	40	40	40	39	34
		EP (g O_2 eq.)	1 980	1 980	1 980	1 950	2 410
		POCP (g ethene eq.)	3.1	3.1	3.1	3.0	3.1
	Yogurt	GWP (g CO_2 eq.)	1 450	1 450	1 450	1 320	1 420
		Energy use (MJ)	8.9	8.7	8.8	8.1	8.2
		EP (g O_2 eq.)	245	245	245	222	297
		POCP (g ethene eq.)	0.50	0.50	0.49	0.45	0.50

Note: GWP = global warming potential; EP = eutrophication; POCP = photochemical ozone creation potentials.

high nitrate loss has two explanations. First, even though the nitrate loss per hectare is lower in organic farming than in conventional farming, the yields are also lower, which means a high nitrate loss per kilogram yield. Second, the two farming practices differ in the choice of concentrate feed. Peas, which have a rather high nitrate leach in relation to yield, are commonly used in organic feed. The conventional farm purchases concentrate feed with a lower nitrate discharge per kilogram of feed (Cederberg and Mattsson 2000).

Discussion

The aim of the study was to identify the measures with the greatest improvement potential for each of the three postfarm actors in the life cycle of dairy products. By collecting data on possible improvements from the actors themselves and from the literature and using these data to recalculate published LCAs on dairy products, we met our aim. We could identify the most efficient action to decrease the total life cycle

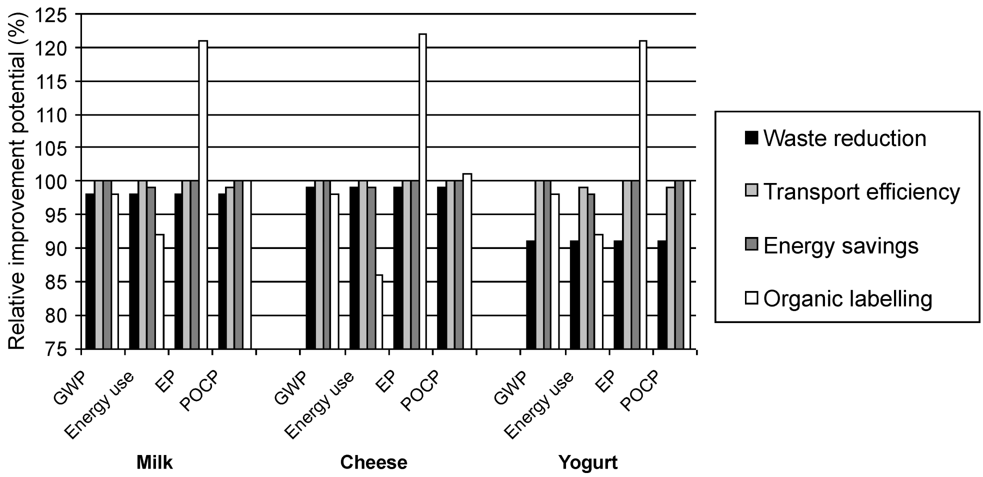

Figure 2 The household's environmental improvement potential to reduce waste, increase transport efficiency, save energy, and buy organic products, in relation to today's environmental life cycle contributions of milk, cheese, and yogurt. 100 represents the present situation; bars lower than 100 mean improvement, and those above 100 mean impairment. GWP = global warming potential; EP = eutrophication; POCP = photochemical ozone creation potentials.

environmental impact for each postfarm actor; for some of these, the improvement potential may not be visible unless a systems approach (i.e., the life cycle perspective) is used. It is important to note that even if each improvement seems small in relative numbers, the dominant part of the environmental impact originates from a system not directly affected by the actors studied—namely, agriculture. Despite this, some of the improvement actions studied led to a 10% decrease in the life cycle environmental impact.

There were a few definite differences in the improvement potential for the products studied. The highest potential was for yogurt, for which waste minimization in particular was effective. Choosing organic products was also effective and generated significant decreases in some impact categories, whereas others were increased. Cheese showed slightly lower potential, and as for yogurt, reducing waste and organic production were the most efficient. The same applied for drinking milk, but the potentials for milk were the least of the three products. The reason for these differences between product types is that the present system for drinking milk is more efficient, as there are large batches, high consumption, and few products in this the category. Cheese, which is produced in smaller batches with a higher degree of processing, still had low losses because of its long shelf life and probably also its higher value per kilogram. Yogurt, finally, is often produced in relatively small batches with a high degree of processing, a very large number of variants, and a shorter shelf life than cheese. The physical characteristics of yogurt, which sticks to surfaces both within the dairy and in packaging, also lead to rather high product losses in today's system.

The choice of an organic product involves an increase in one effect category, which means that the consumer, whether aware of it or not, makes a value-based decision on whether the relatively large improvements in other categories outweigh the negative effect on eutrophication. For the other measures there are no negative effects, but the positive ones for increased energy efficiency and transport optimization are often smaller. The conclusion is that it is unquestionably positive to reduce energy, wastage, and transports, whereas organic products require a value-based choice between environmental impacts.

In this comparison of possible improvements by three actors, the household had by far the greatest improvement potential, followed by the dairy and then the retail sector. This is because households are less efficient today, causing large losses as well as using inefficient home transport and cold storage. The dairy industry can still make improvements, but, because both the processing and the transport are efficient today, the potential for further efficiency is lower in percentage terms. For example, waste from the dairy processing of drinking milk is often reused in production of yogurt or milk powder.

The results might give the impression that the environmental improvement potential for the dairy industry was low, ranging from 1% to 2% decreases of impact for the total life cycle. This is a result of the dominance of agriculture in the life cycle environmental impact of dairy products. Other comparisons may, however, be made. If the effects of reduced wastage at the dairy are instead related only to the dairy's own environmental impact, the proportions are changed. For example, for yogurt, the life cycle effects of decreased waste at the dairy corresponded to a 20% reduction of the dairy's own direct emissions of POCP and a 10% decrease of global warming potential, and the eutrophication avoided was 2.4 times more than the dairy's own emissions of eutrophying substances. Another comparison can be made with the yearly dairy production. A decrease of 2% in the environmental life cycle impact of drinking milk in relation to the Swedish yearly production in 2006 is equivalent to avoiding the environmental impact of 19,040,000 kg drinking milk. For cheese the figure is 2,378,000 kg, and for yogurt it is 5,340,000 kg (Swedish Board of Agriculture 2007).

The system studied is located in Sweden, and we have used contemporary Swedish data on background systems, which affected the results. The most important effect stems from the Swedish average electricity mix, which is made up of approximately 45% hydropower and 45% nuclear power, the remainder being produced from oil and combined heat and power plants that use biofuel (Swedish Energy Agency 2004). If another energy system had been chosen for the quantifications, such as a European mix, the improvement potentials for global warming, eutrophication, and POCP would have been larger for the measure of energy saving.

There are some effect categories relevant to dairy production systems that were not included in this study: biodiversity, toxicity, and landscape aesthetics. These categories are difficult to quantify in product LCA because of methodological problems. Nonetheless, such impacts would not affect the comparisons, except for the choice of eco-labeled products. Drake and Björklund (2001) indicated that organic agriculture has higher biodiversity than conventional methods, which implies that choosing organic products improves the biodiversity. Organic farming also causes less potential toxic impact on the environment, as pesticides are not allowed (Drake and Björklund 2001).

The sources of information about proposed improvements differed for the three types of actors, as did the possibilities for implementation, which should be taken into account. The improved energy efficiency for the dairy was based on a study of the largest Swedish dairy company, which we believe to be well documented (Karlsson et al. 2004). The ease with which it could be implemented might be debatable; it would probably be a long time before the energy savings mentioned could be attained. The potential to decrease the use of energy in retail stores is well documented; because it requires new equipment, it would probably be some time before all equipment was replaced. The change to improved refrigerators in households is based on technology already at hand, which means that the improvement is reasonable within a timeframe determined by the replacement rates for white goods.

The improved transports for distribution require some changes in the management of retail stores, as the delivery of dairy products would have to be extended to a longer period of the working day. This could be implemented, but, because most shopping is done in the afternoon, the workers in grocery stores are generally less available to accept deliveries in the afternoon than in the morning and at midday; hence, the deliveries could require shifting more work time to afternoons. The eco-driving assumed could be implemented rather quickly, because many haulers are already educating their drivers to save fuel and improve their environmental performance. The improved home transport is more complex. We have assumed more efficient vehicles and less frequent shopping. The recent trend is rather that the fuel consumption per kilometer is constant, but with rising fuel prices the interest in high-mileage cars will probably increase. The options for shopping less frequently are debatable. We have not found any data on this in the literature, but the common perception in Sweden is that the trend is most likely the opposite, that the shopping frequency is rising. Consumer behavior is difficult both to measure and to predict, as it is influenced by many structural changes in society, such as the concentration of retail stores to large shopping malls in remote areas, as well as the income and overall workload of families.

The decreases of product losses assumed in the study were all based on relatively small changes in the system. Hence, none of the improvements required structural changes. This means that the implementation could be rather easy and without costs; actually, all of the actors saved money by reducing product losses. The data on product losses are less well documented, however, especially the losses in households. The study conducted was limited, and it simply indicated the magnitude of the losses. For the quantification of waste in grocery stores, we have included only the products returned to the dairy, whereas, in reality, some dairy products are discarded as waste. Although the amount is not known and probably differs between stores, it could be large, which would affect the conclusions. Overall, the improvement in reducing waste is conservative here, in the sense that low potentials were assumed. Larger improvements could probably be achieved, but they would demand more changes in the system. The choice of organic products can easily be made by the consumer, as those products studied are available from both types of farms.

Generally, the most uncertain data are in the household part. The reasons are twofold; first, it is a less researched area, so the absolute values are uncertain. The second reason, which affects home transport and cold storage, is the complexity with which these activities are carried out. When people are shopping, they buy a large number of products at the same time, and often they do other errands during the same shopping trip; hence, the fuel consumption for the car has to be allocated to the studied product. This can be done in different ways, which affects the result. The same applies to cold storage: A number of products are stored in the refrigerator, and the energy use must be allocated. Data for the other activities in the life cycles are less uncertain.

In terms of data quality, the data for the household activity are the least solid. Hence, the results for improvements for the household are less significant, except for the option to buy organic products. The results for the other actors are judged to be more solid, as the data quality is higher.

The improvements analyzed can, of course, be combined. Because we avoided analyzing actions that involved large changes in the system, there were no conflicts between them; it is possible to decrease waste, use energy more efficiently, minimize transports, and buy organic milk at the same time. If all of the measures were implemented simultaneously, the total improvement would, of course, be much larger than the ones reported in this study.

The method used in this study rests on the availability of reliable LCA data on the production system combined with good estimations of the improvement potentials. The method can probably be applied also to more far-reaching changes of the system, albeit with a greater degree of uncertainty. Among such changes that could be of interest to study are structural developments, such as centralization or decentralization of agriculture, the dairy industry, and retailers. The range of actors in such a study would then have to be expanded to include others with more of a branch perspective (e.g., dairy and retail companies, as opposed to specific production sites), as well as policy makers (e.g., city planners).

Two aspects of methodology are highlighted by this study. One is the necessity of the systemic approach, the life cycle perspective, to describe the full effect of a potential improvement, in particular reducing waste. Lowering waste decreases all inputs and emissions needed upstream in the system; hence, waste avoided later in the chain is more important than that avoided earlier in the life cycle. The second is the usefulness and feasibility of the actor analysis. LCA studies are often interpreted with dominance and contribution analyses—that is, what life cycle phases and particular environmental loads (emissions and resource consumptions) contribute the most to the overall results. In LCA there are seldom interpretations of the sphere of influence of the various actors along the product chain, which gives a concrete example of the need for the inclusion of actors in industrial ecology noted by Andrews (2000). This study has demonstrated the feasibility of such an approach, showing that the life cycle environmental implications of improvement potentials may be quantified on an actor basis.

Conclusions

Using a systems perspective is crucial for this type of environmental analysis, but it is important to realize that even small life cycle improvements by each actor can represent large savings in comparison with the actor's own separate environmental impacts.

The most efficient improvement actions for the dairies, retailers, and households are listed here.

- For the dairy, no improvement action was clearly superior to the other, but reducing waste appeared to contribute to a lower environmental impact for most impact categories for all three products.
- For the retailer, decreased use of energy for cold storage and display seemed to be the most efficient improvement action.
- For the household, reducing waste was the improvement action that gave clearly positive results for all effect categories included. When households chose organic products, the improvements in energy use for milk and cheese appeared to be even greater, but the eutrophication rose.

Overall, the household has the largest improvement potential, and yogurt is the product that offers the greatest improvement. The improvement actions analyzed in this study can be combined, which thus enlarges possible improvements.

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Notes

1. Editor's note: For a discussion of similar trends in the U.K. yogurt industry, see the work by Dewick and colleagues (2007).
2. One kilowatt-hour $\approx 3.6 \times 10^6$ J (SI) $\approx 3.412 \times 10^3$ BTU. One square meter (SI) $\approx 10.76\,\text{ft}^2$.
3. In 1999, SEK 1 $\approx$ €0.114 $\approx$ \$0.121.

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