LCA Case Studies

The role of flexible packaging in the life cycle of coffee and butter

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Abstract

Background, Aim, and Scope.

The evaluation of packaging's environmental performance usually concentrates on a comparison of different packaging materials or designs. Another important aspect in LCA studies on packaging is the recycling or treatment of packaging wastes. LCA studies of packed food include the packaging with specific focus on the contribution of the packaging to the total results. The consumption behaviour is often assessed only roughly. Packaging is facilitating the distribution of goods to the society. Broader approaches, which focus on the life cycle of packed goods, including the entire supply system and the consumption of goods, are necessary to get an environmental footprint of the system with respect to sustainable production and consumption.

Methods.

A full life cycle assessment study has been conducted for two food products: coffee and butter packed in flexible packaging systems. The aim was to investigate the environmental performance of packaging with respect to its function within the life cycle of goods. The study looks at the environmental relevance of stages and interdependencies within the life cycle of goods while taking consumers' behaviour and portion sizes into consideration. The impact assessment is based on the following impact categories: non-renewable cumulative energy demand (CED), climate change, ozone layer depletion (ODP), acidification, and eutrophication.

Results.

The study shows that the most relevant environmental aspects for a cup of coffee are brewing (i.e. the heating of water) and coffee production. Transport and retail packaging are of minor importance. Brewing and coffee production have an impact share between 40 percent (ozone layer depletion, white instant coffee) and 99 percent (eutrophication, black coffee). Milk added for white coffee is relevant for this type of preparation. The instant coffee in the one-portion stick-pack needs more packaging material per cup of coffee and is prepared by a kettle with lower energy demand, such as a coffee machine, thus leading to higher shares of the retail packaging in all indicators. A one-portion stick-pack can prevent wastage and resources related to coffee production can be saved.

The most relevant aspect regarding the life cycle of butter is butter production, dominated by the provision of milk. Over 80% of the burdens in butter production stem from the provision of milk for all indicators discussed. Regarding climate change, methane and dinitrogen monoxide, emissions of milk cows and fodder production are most relevant. Fertilisation during livestock husbandry is responsible for most burdens regarding acidification and eutrophication. The distribution and selling stage influences the indicators CED and ODP distinctly. The reasons are, on the one hand, the relatively energy intensive storage in supermarkets and, on the other hand, the use of refrigerants for chilled storage and transportation. The storage of butter in a refrigerator for 30 days is responsible for about 10% of the cumulative energy demand.

Discussion.

Several aspects have been modelled in a sensitivity analysis. The influence of coffee packaging disposal is very small due to the general low influence of packaging. In contrast, the brewing behaviour is highly relevant for the environmental impact of a cup of coffee. That applies similarly to the type of heating device – i.e. using a kettle or an automatic coffee machine. Wastage leads to a significant increase of all indicators. Under the wastage scenario the coffee from one-portion stick-packs has a considerable better environmental performance concerning all indicators because, in case of instant coffee wastage of hot water and in case of ground coffee wastage of prepared coffee, has been predicted. Regardless of urban or countryside distances, grocery shopping has a low impact.

The storage time of butter is relevant for the results in the indicator non-renewable cumulative energy demand. This is mainly the case when butter is stored as stock in the freezer. The end of life treatment of the packaging system has practically no influence on the results. Grocery shopping is of limited importance no matter which means of transport are used or which distances are regarded. Spoilage or wastage is of great importance: a spoilage/wastage of one third results in about 49 percent increased impacts compared to the standard case for all indicators calculated.

Conclusions.

The most important factors concerning the environmental impact from the whole supply chain of a cup of coffee are the brewing of coffee, its cultivation and production, and the milk production in case of white coffee. The study highlights consumer behaviour and packaging related measures to reduce the environmental impact of a cup of coffee.

The most relevant measures reducing the environmental impacts of butter consumption are the optimisation of the milk and butter production. Another important factor is the consumers' behaviour, i.e. the reduction of leftovers. The consumer can influence impacts of domestic storage using efficient and size adequate appliances. The impacts of packaging in the life cycle of butter are not of primary importance.

Recommendations and Perspectives.
This study shows that in case of packaging industry a reduction of relevant environmental impacts can only be achieved if also aspects indirectly influenced by the packaging are taken into account. Thus, the packaging industry should not only aim to improve the production process of their packages, but also provide packages whose functionality helps to reduce other more relevant environmental impacts in the life cycle such as, for example, losses. Depending on the product, tailor-made packaging may also help to increase overall resource efficiency.

Keywords:
Brewing; butter; coffee; cold storage, consumer behaviour; espresso; flexible packaging; food products; milk; packed goods

1 Introduction

The evaluation of the environmental performance of packaging usually concentrates on a comparison of different packaging materials or types of packaging designs (De Monte et al. 2005, Hunt 1974, Plinke et al. 2000, Schmitz et al. 1995). Another important aspect in LCA studies on packaging is the recycling or treatment of packaging wastes (Arena et al. 2003, Heyde & Kremer 1999, Perugini et al. 2005). Several LCA databases were provided for different packaging materials (Habersatter et al. 1998, Hischier 2007, Hischier et al. 2004). LCA studies of packed food goods often include the packaging with specific focus on the contribution of the packaging to the total results (Jungbluth et al. 2000). The consumption behaviour is often assessed only roughly.

Aspects going beyond this narrow view on the packaging itself, like the consumption and production of packed goods, are often neglected if different packages are compared directly. The functional role of packaging is facilitating the distribution of goods to the society to satisfy human needs. Broader approaches, which focus on the life cycle of packed goods, including the entire supply system and the consumption of goods, are necessary to get an environmental footprint of the specific packaging system with respect to sustainable production and consumption.

Since the reason to produce packaging is to enable the consumer to consume products, the relevant question from a sustainability point of view must be to optimize the sustainability along the total supply chain of consumer goods rather than focusing only on parts of it.

This was the starting point for a recently conducted study about the function of flexible packaging within a life cycle assessment of packed food products in Europe (Büsser et al. 2008). Flexible packaging is defined as a packaging involving pliant materials. It encompasses but is not limited to bags, pouches, labels, liners, and wraps utilizing paper, plastic film, aluminium foil, metallised or coated paper, plastic film, or any combination of these materials. This study was commissioned by Flexible Packaging Europe (FPE), a division of the European Aluminium Foil Association (EAFA).

2 Methods

2.1 Questions addressed

The goal of this study is to investigate the following:

- The environmental performance of flexible packaging with respect to its function within the life cycle of goods, i.e. within the supply chain of goods and the consumption of goods.
- The role of flexible packaging with respect to resource efficiency and prevention of spoilage and wastage of packed goods.
- The environmental relevance of stages and interdependencies within the life cycle of goods while taking consumers' patterns and portion sizes into consideration.

The study should illustrate the environmental relevance of flexible packaging with regard to the consumption of selected nourishing goods in Europe. Results of this study are not always transferable to other packaging systems or types of products.

2.2 Investigated products

The case studies were chosen to represent different types of flexible packaging as well as a range of products. These case studies are:

- Ground and instant coffee in pouches and stick-packs made of plastic laminate with an aluminium foil layer as a barrier

- A family and single portion pack of butter wrapped in a laminate with an aluminium foil layer

Characteristics of the packaging are shown in the section 3.1 (coffee) and 4.1 (butter), respectively.

2.3 Data origin of LCI analysis

The foreground inventory data stem from our own measurements (e.g. electricity consumption of coffee machines and kettles, weight and measures of packaging, cooking time, etc.). They are discussed in the next section.

The primary sources of background inventory data for the life cycle inventory analysis (LCI) in this study are:

- The ecoinvent data v2.01 (ecoinvent Centre 2007), which contains inventory data for many basic materials and services,
- a report containing life cycle inventories for processes in the packaging industry (Habersatter et al. 1998),
- a Ph.D. thesis investigating the environmental impacts of several food products including vegetables and whole milk (Jungbluth 2000). The data have been partly updated and linked to the ecoinvent v2.01 background data (Jungbluth et al. 2008).

Priority was given to the ecoinvent data where possible, because they are assumed to be more up to date, more thoroughly reviewed and, therefore, more reliable. All calculations and the analysis of results were conducted with the LCA software SimaPro 7.1 (PRé Consultants 2007).

2.4 Environmental indicators

The results of this study are calculated for eight environmental indicators based on the CML 2001 method (Guinée et al. 2001b, a). The main impact assessment and discussion is based on five indicators which are:

- Cumulative energy demand (CED), non-renewable (MJ-eq.)
- Climate change (kg CO_2-eq.)
- Ozone layer depletion (ODP) (kg CFC-11-eq.)
- Acidification (kg SO_2-eq.)
- Eutrophication (kg PO_4^{3-}-eq.)

The remaining indicators (renewable CED, abiotic depletion, photochemical oxidation, human toxicity, and freshwater aquatic toxicity) were evaluated as well but not discussed separately, as they often do not provide additional insights. In those cases where they become relevant, this is mentioned and discussed in the study (Büsser et al. 2008).

3 Case Study: Coffee

The functional unit for the coffee life cycle is defined as 'one cup of coffee ready to drink at home or in small offices'.

3.1 Life cycle inventory analysis

The life cycle inventory for coffee encompasses the whole food supply system from the cultivation, processing, packaging, and transportation of the coffee beans to production and packaging of ground and soluble coffee, transport to retailers and households, and the brewing ending with a cup of coffee ready to drink (Büsser et al. 2008). The growing as well as the first stages of coffee processing occurs commonly in countries near the equator due to climatic reasons. This study investigated coffee production in Brazil based on different sources (among others Coltro et al. 2006, Diers et al. 1999, EPA 1995). Most of the coffee, however, is consumed in the industrialised countries (e.g. Europe).

As water vapour and oxygen reduce the quality of coffee, its packaging material consists of laminate with a number of layers made of different materials to prevent the diffusion of these substances through the packaging. Investigated is ground coffee packed in a 500g aluminium foil bag and instant coffee packed in aluminium foil containing sticks. Fifteen sticks are packed in one cardboard box.

The structure of coffee packaging is shown in Table 1, its composition in Table 2.

Table 1: Structure of the investigated coffee packaging. The specific weight is calculated.

		Ground coffee	Instant coffee	
		500g bag	Cardboard box	Stick
Length x width	cm^2	32.6 x 30.5	24.4 x 17.4	12.0 x 5.0

Area (to be printed)	cm^2	994.3	425	60
Weight	g	12.9	12.7	0.522
Specific weight	g/m^2	130.0	299.0	87.0
Average amount of coffee per stick	g			1.93

Table 2: Material composition of the packaging of ground and instant coffee.

	Material	Aluminium foil bag		Aluminium foil stick	
		Thickness (µm)	Weight (g/m^2)	Thickness (µm)	Weight (g/m^2)
Outer layer	PET	12	16	12	16
Middle layer	Alu foil	7	19	7	19
Inner layer	PE	100	94	55	64
Total		119	129	74	83
Source	Qingdao Yongchang Suye Co., Ltd.[1]			Our own estimation based on weight measurements and ground coffee packaging	

Investigated were different kinds of coffee preparation within espresso made from ground coffee and white coffee made from instant coffee. The amount of coffee needed to brew a cup of coffee is constant (7 grams for ground coffee and 2 grams for instant coffee) but the amount of hot water used depends on the desired type of coffee (30 grams for espresso and 125 grams for conventional coffee). For white coffee 40 grams of milk are used.

3.2 Impact assessment

The impact assessment of coffee consumption includes a standard scenario for coffee made from ground or instant coffee with water and eventually milk, as well as different wastage, packaging disposal, and consumer behaviour scenarios. The standard case assumes: average roasted coffee in a roastery with emission control, brewing ground coffee by an automatic coffee machine, heating the water for instant coffee by a kettle, normal user behaviour concerning coffee machine switch off, and a PET/Al/PE bag as packaging. The adding of sugar is not considered in all cases. Table 3 shows the most important parameters, which are also modified in a sensitivity analysis.

Table 3: Overview of the parameters in the standard case of coffee and modified in the sensitivity analysis.

Scenario	Parameter	Standard case	Scenarios
Packaging disposal	Aluminium foil bag/stick Cardboard box	Incineration Recycling	Landfill Landfill
Brewing behaviour	Excess water Electricity use (kWh/l)	75% 0.22	10% or 150%, economic and negligent 0.14 or 0.31, economic and negligent
Brewing device	Ground coffee Instant coffee	Coffee Machine Kettle	Kettle Kettle
Wastage	Coffee or water not consumed	No leftovers	33 % wastage
Grocery shopping	Distance (km) Share car (%)	4.8 84%	Urban (2.4 km) and countryside (9.7 km) scenario 40% and 95%, respectively
Favourable behaviour		As above	Economic user behaviour, kettle, no spoilage, packaging is incinerated, urban grocery shopping scenario
Unfavourable behaviour		As above	Negligent user behaviour, coffee machine, spoilage, packaging is landfilled, countryside grocery shopping scenario

Fig. 1 shows the results of the standard case for a cup of coffee with regard to the non-renewable cumulative energy demand. A cup of espresso causes the lowest energy demand mainly due to the lower amount of hot water used. Instant coffee is prepared by a kettle and thus needs less energy for brewing than the preparation by a coffee machine. The energy demand ranges between 0.7 MJ-eq and 1.9 MJ-eq for one cup of coffee. The large differences between different options can mainly be explained by different amounts of water and milk used for the preparation and the brewing device (coffee machine vs. kettle).

[1] http://yong.en.alibaba.com/product/50141440/51711955/Compounded_Packaging/Coffee_Bag.html

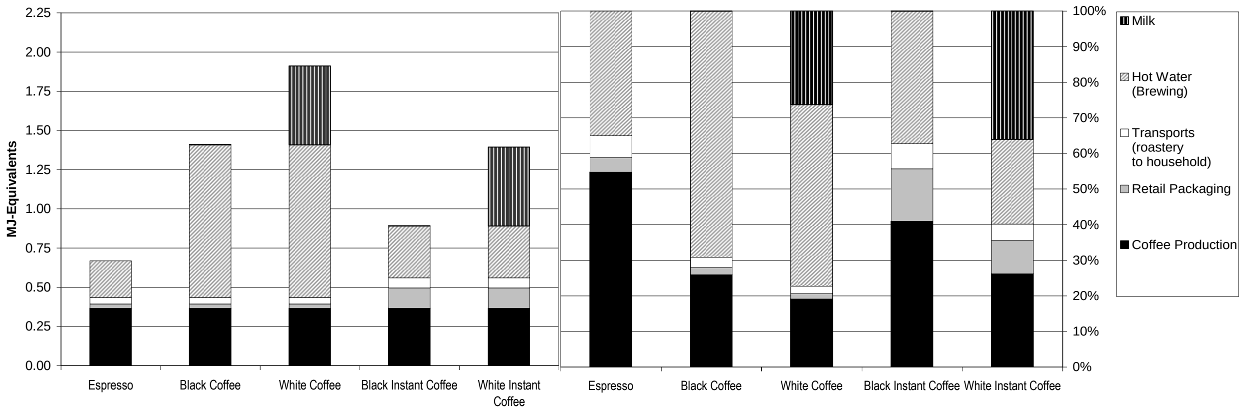

Fig. 1: **Results of the standard case for a cup of coffee with regard to the non-renewable cumulative energy demand. Left are shown the absolute values, on the right side the results are scaled to 100 %.**

Fig. 2 shows the results of the standard case for a cup of coffee with regard to climate change. The white coffee has the highest impact with nearly 180 grams CO_2-eq per cup of coffee. The lowest result is for the black instant coffee with only 80 grams CO_2-eq.

The study shows that the most relevant environmental aspect for a cup of coffee is brewing (i.e. the heating of water) and coffee production. Transport and retail packaging are of minor importance. Brewing and coffee production have a considerable impact share between 40 percent (ozone layer depletion, white instant coffee) and 99 percent (eutrophication, black coffee). In the case of white coffee, the added milk is of great environmental relevance. The instant coffee in the one-portion stick-pack is prepared by a kettle with lower energy demand, such as a coffee machine, but needs more packaging material per cup of coffee, thus leads to higher shares of the retail packaging in all indicators.

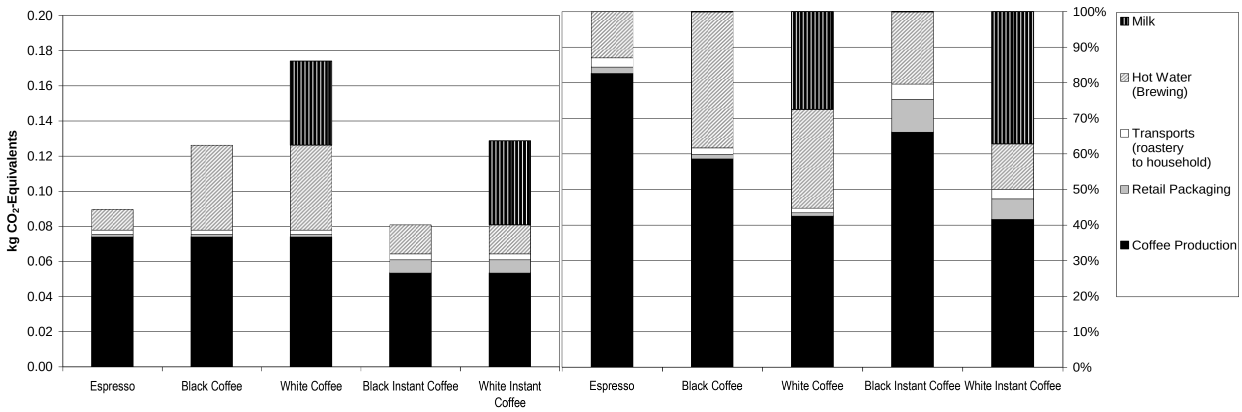

Fig. 2: **Results of the standard case for a cup of coffee with regard to climate change. Left are shown the absolute values, on the right side, the results are scaled to 100 %.**

3.3 Sensitivity analysis

A sensitivity analysis is conducted in Fig. 3 regarding the parameters shown in Table 3. The influence of packaging disposal is very small due to the general low influence of packaging. In contrast, the brewing behaviour is highly relevant for the environmental impact of a cup of coffee. That applies similarly to the type of heating device – i.e. using a kettle or an automatic coffee machine. Wastage leads to a significant increase in all indicators. Under the wastage scenario, the coffee from one-portion stick-packs has a remarkably better environmental performance concerning all indicators, because of the predicted hot water and prepared coffee wastages for instant coffee and ground coffee, respectively. It is assumed that a one-portion stick-pack can prevent wastage or over-consumption, thus saving resources related to coffee production. Regardless of urban or countryside distances, grocery shopping has a low impact.

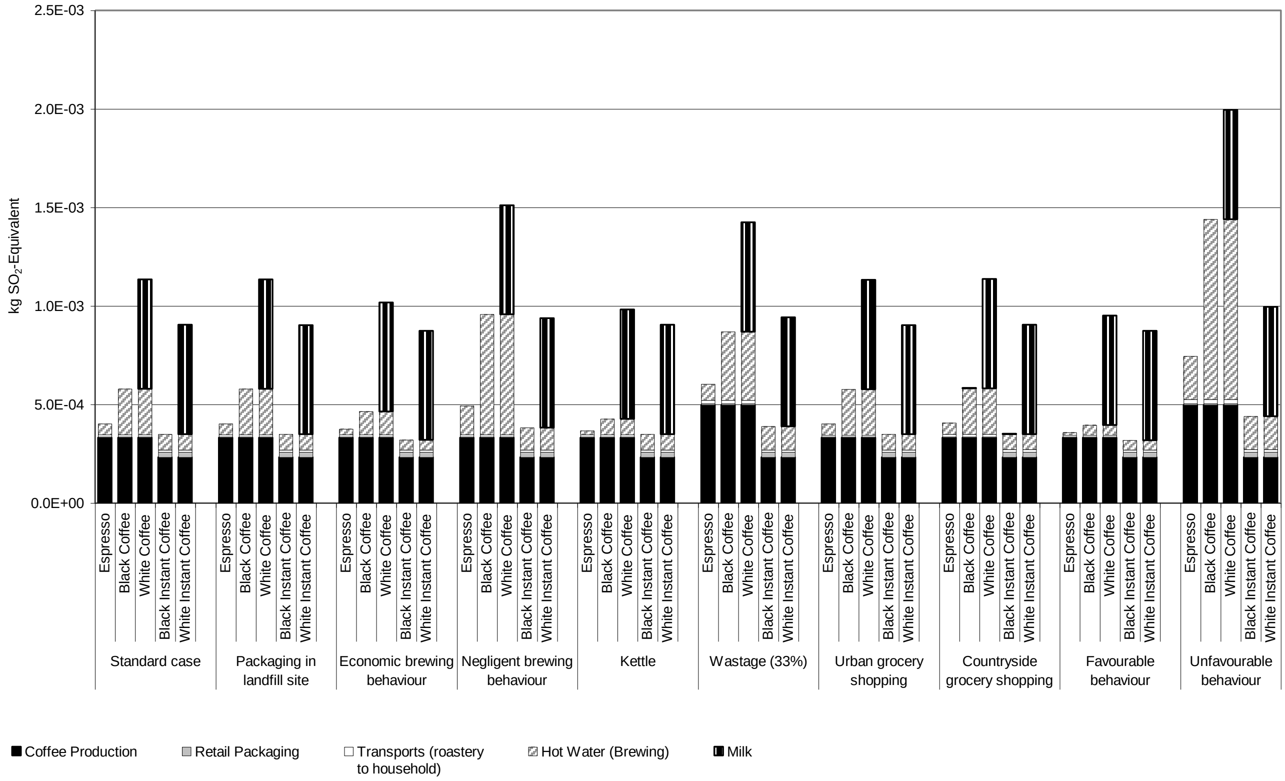

Fig. 3: Sensitivity analysis with regard to acidification. Shown in absolute values per cup of coffee.

3.4 Data Quality and Uncertainties

Some uncertainties may have a relevant impact on the evaluation. The results for espresso can be considered as an underestimation due to the way the impact from brewing is determined. This is especially the case for coffee machines (the most pronounced in the case of negligent user behaviour), where only a low share of the energy consumed is really used for heating the water. An allocation based on number of cups might lead to a more appropriate comparison in these cases. However, this becomes less of an issue when a kettle is used and when the user shows an economical behaviour.

Even though coffee production is one of the main environmental aspects, only the production in Brazil is considered in the evaluation. It is clear that other countries may have a differing agricultural production due to other climatic conditions, higher mechanisation or other strains of coffee plants. Further uncertainties come from applying average European emission factors for the application of pesticides and fertilisers to an area with differing agricultural practices, climatic conditions, and soil properties. The knowledge regarding this uncertainty issue is very limited and, therefore, not easily assessable.

The data used for packaging lamination, cutting and printing are about 10 years old. It must be expected that on the one hand the processes have evolved leading to lower environmental impacts per processing step. On the other hand, some packaging may have become more complex in processing (i.e. more layers, more different materials) which presumably leads to an increase of the environmental impact that has not been considered either. In general there have been significant improvements in printing and laminating equipment since 1998. Therefore, it is more likely that the environmental impacts for packaging processing are overestimated.

As long as the differences in the indicators are pronounced – such as the minor importance of packaging and transports vs. the major importance of brewing and coffee production in the case of most indicators – it is possible to draw some conclusions despite the limitations mentioned.

3.5 Conclusions

Consumed coffee is a rather complex product as it involves not only the direct purchase of a product from the supermarket, but also the further preparation including brewing of coffee at the household or the office.

The most relevant factors concerning the environmental impact from the whole supply chain of a cup of coffee are for the majority of indicators:

- The brewing of the coffee,
- the coffee production (cultivation, coffee berry processing, coffee bean roasting and instant coffee production if applicable),
- and the milk production in case of white coffee.

The most relevant measures reducing the environmental impact of a cup of coffee are described below. It was not possible in this study to exactly determine the present consumer behaviours regarding wastage or economic user behaviour. Thus, it was not possible to exactly rank the measures, because such a ranking would be dependent on the consumer behaviour, the indicator, and the type of coffee.

- **Economic user behaviour**; i.e. switching the machine on only when needed, reducing the stand-by electricity consumption by removing the plug from the power socket or buying a coffee machine without stand-by consumption and with energy efficient heating.
- **Using a kettle instead of a coffee machine**; the kettle is intrinsically fulfilling the before mentioned aspects of reducing the electricity consumption, however, convenience and coffee experience aspects may not always allow one to substitute a coffee machine with a kettle.
- **Reducing leftovers of brewed coffee** avoids wastage of coffee in its drinking form and wastage of hot water. This can be achieved with a coffee machine producing single cups or with a good planning of the amount of necessary coffee. However, this might not be an appropriate option during business meetings or not feasible when a large number of coffees have to be served in a short time. Using instant coffee and hot water in thermos flasks can be a suitable option in such cases, although not all consumers consider instant coffee an acceptable substitute for coffee made from ground beans.
- **Minimising the amount of packaging;** the cardboard box for the instant coffee packaging has a not negligible influence on the impacts of packaging (18% of non-renewable cumulative energy demand) for some indicators. This part of packaging could be optimized.
- **Optimize the amount of packaging** by choosing adequate packaging sizes. As coffee hardly deteriorates if appropriately stored, it might be worthwhile to buy larger (refill) bags, instead of proportioned coffee. However, some people may avoid coffee that is stored too long in an open bag because it loses its flavour. In these cases sticks might be favourable.

The optimisation potential in the cultivation of coffee was not assessed in detail, nevertheless, it can be concluded from the results that organic coffee production could lead to a reduction with regard to freshwater aquatic toxicity due to minimal application of pesticides. Yet, the reduced yields expected with organic production may cause negative effects due to expansion of the agricultural area and a higher machinery use.

Discussions regarding the environmental impact from food products often lead to statements highlighting either the importance of reducing (unnecessary extensive) packaging, the thermal utilisation of packaging waste, the recycling – or all of them. The environmental impact from the packaging, though low, is not negligible (especially for instant coffee in single serving packaging). However, compared to the reduction potential of other measures (e.g. economic coffee machine utilisation) it is not considered to be of primary importance at the moment for this type of product. Consumer's behaviour influences the environmental impacts of coffee consumption much more than the type of packaging.

As the coffee supply chain is currently in a progress of environmental improvements, e.g. energy-optimised coffee machines or increasing interest in organic coffee (global sales of organic coffee increased at 56 percent from 2003 to 2006[2]), the relative share of the packaging in the environmental assessment is expected to increase if there is no corresponding optimisation with regard to this aspect.

4 Case Study: Butter

The functional unit concerning butter in this study is 'the provision of one kilogramme of butter ready to be eaten at home'.

4.1 Life cycle inventory analysis

The life cycle of butter encompasses the whole food supply system from the milk production to the storage of butter in the consumer's refrigerator. The process steps in the production range from the separation of raw milk into low fat milk and cream to the pasteurisation of cream, cooling, ripening, and churning (Büsser et al. 2008).

Butter has to be wrapped in a greaseproof material that is impervious to light, flavouring and aromatic substances. The analysed packaging consists of three layers (aluminium foil, synthetic wax and paper). The packaging system shown in this

[2] www.ota.com, Organic Trade Association

study represents the flexible packaging of one butter-cube of 250 gram and 15 gram, respectively. Its specification and composition are shown in Table 4 and Table 5.

Table 4: Characteristics of the packaging system for 250 gram and 15 gram butter cubes.

	Unit	250g packaging (minimum)	250g packaging (maximum)	15g packaging	Remark
Butter weight	kg	0.25	0.25	0.015	
Length x Width	cm	14.5x24.5	18.5x23.0	7.8x9.5	
Area	cm^2	355.25	425.50	74.10	
Area to be printed	cm^2	284.20	340.40	59.28	Assumption: 80% is printed
Weight	g	2.30	2.80	0.48	
Volume	litre	0.241	0.241	0.014	Own measurements

Table 5: Butter packaging material composition.

	Material	Thickness (μm)	Weight (g/m^2)	Remark/Source
	Lacquer NC-base		0.6	FPE
	Lacquer PET-base		0.6	FPE
1. Layer	Aluminium, Leg 8079	6.35	18.8	Own calculation of weight
2. Layer	Wax (microcrystalline)		10.0	FPE
3. Layer	Paper (greaseproof and wet proof)		35.0	FPE
Total			65.0	

In this study, conventional butter without any ingredients (e.g. salt) is considered. Butter is stored and transported under chilled conditions. The cold chain consists of the cold store, the supermarket and refrigerated transports. At home butter can be stored in a refrigerator up to one month, but some consumers may freeze and store butter for a longer period. Modelled electricity consumptions in the cold chain are shown in Table 6.

To produce one kilogramme of butter between 20 and 25 litres fresh milk or between 2.3 and 2.5 kilogramme cream is used[3,4] (Nielsen et al. 2003, Schweizer Milchproduzenten 2007). Høgaas-Eide (2002) investigated milk inputs and products of a small dairy. From that study it is calculated that 16 litre of milk are needed to produce one kilogramme of butter. In the standard scenario, 22.5 litre milk/kg butter is assumed, in further scenarios 16 and 25 litres/kg are investigated.

Table 6: Modelled electricity consumption in the different life cycle stages.

Location	Unit	Electricity consumption	Remarks / Assumptions
Cold store	kWh/kg	0.017	According to (Kjer et al. 1994), Studie J, Anhang 4 from Faist (2000): 30 days of storage and 0.002 MJ/(kg*d) energy consumption for fresh food (milk, cheese) in a cold store
Supermarket	kWh/kg	0.70	Average from Foster et al. (2006) and Faist (2000), includes energy consumption for cooling and other purposes.
Domestic refrigerator	kWh/kg	0.79	Steiner et al. (2005) reports an energy consumption of 194 kWh/a for a cooling volume of 284 litres. Assumed is a storage time of 30 days and 20 kg of cooled products in the refrigerator.
Domestic freezer	kWh/kg	5.07	According to producer's information energy consumption of a B-class freezer* is 0.0059 kWh/l/d. Assumed is a storage time of 180 days and a load of 0.2 litre food products per litre storage volume (Faist 2000).
Refrigerated road transport	kWh/tkm	0.125	Adapted from Heap (2003), only for cooling
Refrigerated rail transport	kWh/tkm	0.015	Adapted from Heap (2003), only for cooling

*In Switzerland refrigerators and freezers are labelled with energy etiquettes. Considered are energy consumption and cubic capacity. The best etiquette is A++ and the worst is G.

4.2 Impact assessment

The assessment of butter consumption includes a standard case with the following assumptions: average production of

[3] http://www.milkingredients.ca/dcp/article_e.asp?catid=145&page=216 (12.11.2007)
[4] http://www.schweizerkueche.ch/site/div/pdf/butter/butter_de.pdf (12.11.2007)

butter (i.e. 22.5 litres of milk to produce one kilogramme of butter), packaging is incinerated, industrial and commercial distribution: refrigerated storage and transportation between 0 and 4°C, domestic storage: 30 days in refrigerator, no spoilage or wastage of butter. A sensitivity analysis is conducted regarding the parameters shown in Table 7.

Table 7: Overview of the parameters in the standard case and modified in the sensitivity analysis of butter consumption.

Parameter	Parameter	Standard case	Scenario
Domestic storage	Days in refrigerator	30	No storage / 180 days in freezer and 30 days in refrigerator
Packaging disposal	Whole packaging	Incineration	Landfill
Grocery shopping	See Table 3	Average distances	Urban and countryside scenario
Spoilage/wastage		No spoilage/wastage	33% spoilage/wastage
Favourable behaviour		As above	22.5 litres milk input, no domestic storage, packaging is incinerated, urban grocery shopping scenario, no spoilage/wastage
Unfavourable behaviour		As above	22.5 litres milk input, 180 days storage in freezer and 30 days in refrigerator, packaging is landfilled, countryside grocery shopping scenario, including spoilage/wastage scenario
Butter production	Litre milk input	22.5	16 litre / 25 litre milk input

Fig. 4 shows the split up of environmental impacts between different stages in the life cycle of butter with regard to the selected five impact categories. Over 85% of the burdens in butter production stem from the provision of milk for all indicators discussed. Methane and dinitrogen monoxide emissions of milk cows and fodder production are most relevant regarding climate change. Fertilisation during livestock husbandry is responsible for most burdens regarding acidification and eutrophication. The distribution and selling stage influences the indicators CED and ODP distinctly. The reasons, on the one hand, are the relatively energy intensive storage in supermarkets and, on the other hand, the use of refrigerants for chilled storage and transportation. In case of CED the storage of butter in the refrigerator for 30 days is responsible for about 10% of the total impacts.

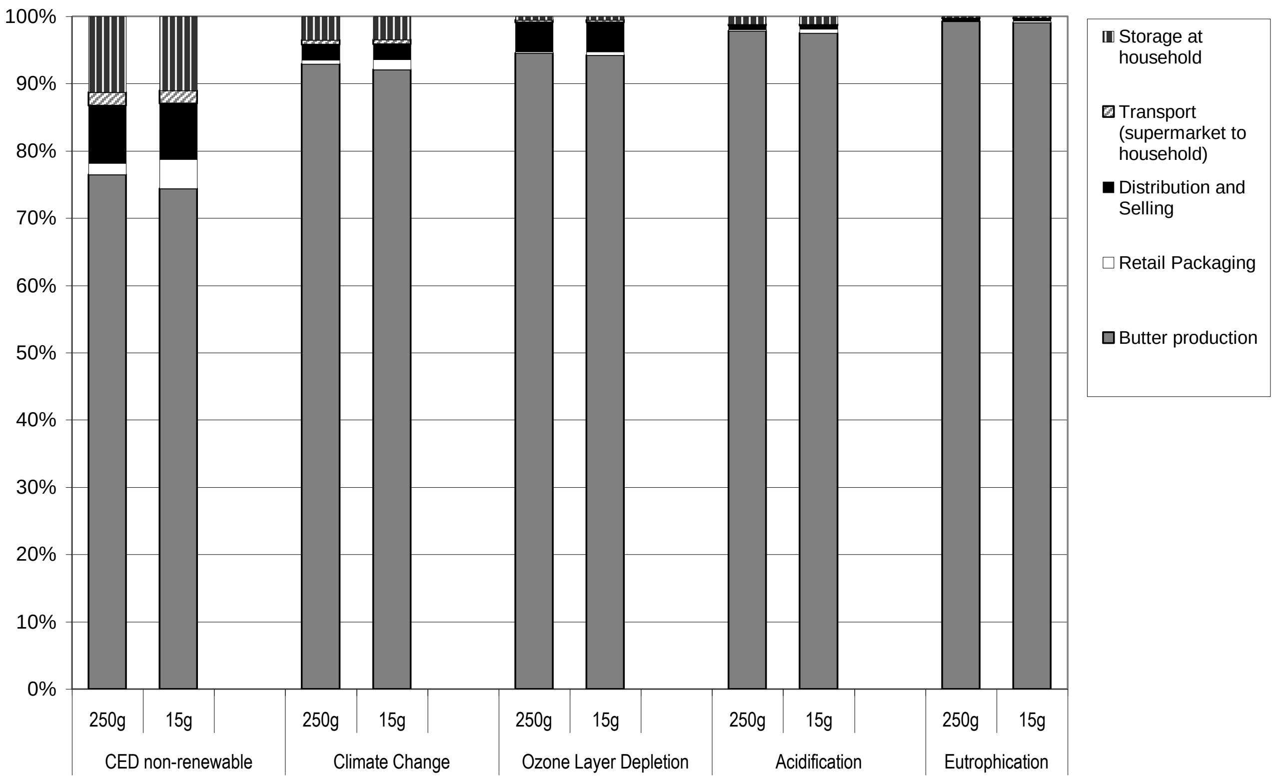

Fig. 4: Results of the standard case for one kilogramme butter with regard to the selected five indicators. The results are scaled to 100 %.

With regard to the indicators shown, the impact of packaging varies between 0.07 percent for eutrophication and 1.4 percent for non-renewable cumulative energy demand in case of the 250-gram packaging system. If butter is served in smaller amounts, i.e. 15 grams packages, the influence of packaging increases for all indicators due to the higher amount of packaging material used to pack one kilogramme of butter (0.19 percent in case of eutrophication and 3.5 percent in case of non-renewable CED). In general, the environmental impact of packaging is of minor importance compared to butter production, storage at home, and distribution and selling processes. Influence of butter transportation packaging is less than 0.1 percent to the whole life cycle of butter consumption.

4.3 Sensitivity analysis

The sensitivity analysis in Fig. 5 compares the modified parameters to the standard scenario as described in Table 7. The differences between the unfavourable behaviour scenario and the standard scenario originate mainly from the spoilage/wastage scenario and domestic storage. The differences between the favourable behaviour scenario and the standard scenario are small, because butter production is not influenced and no spoilage or wastage was assumed for the standard case.

The storage time of butter is relevant for the results in the indicator non-renewable cumulative energy demand. This is mainly the case when butter is stored as stock in the freezer. In contrast, the end of life treatment of the packaging system has practically no influence on the results. Again, grocery shopping is of limited importance no matter what means of transport is used or which distances are regarded. Spoilage or wastage is of great importance: a spoilage/wastage of one third results in an increase of the impacts of about 49 percent compared to the standard case in case of all indicators calculated.

Unsurprisingly, the less milk is used to produce butter the lower are the environmental impacts in all indicators. The maximum share of packaging is 5% for non-renewable CED and 15-grams packaging systems.

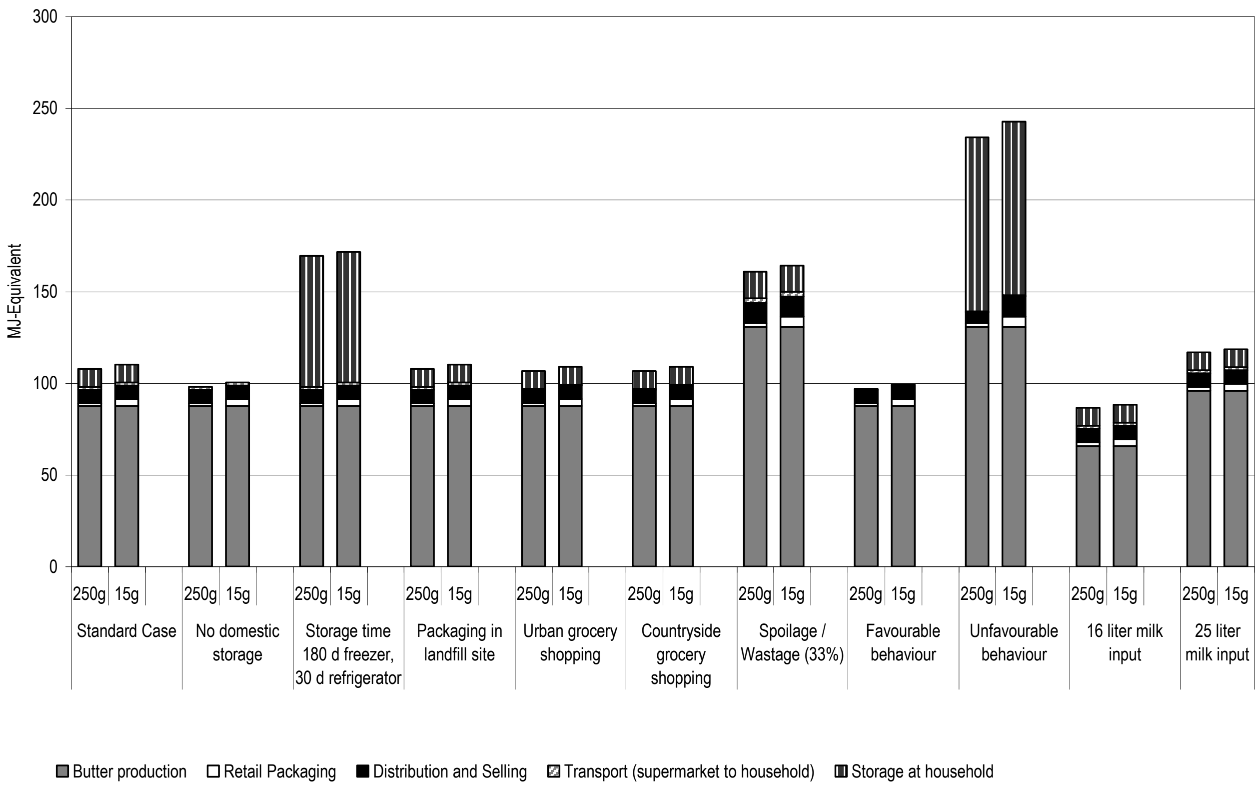

Fig. 5: Sensitivity analysis with regard to non-renewable cumulative energy demand. Shown in absolute values for 1 kg butter.

4.4 Data Quality and Uncertainties

Some uncertainties may affect the evaluation. The main influence stems from the butter production. The underlying data are based on an environmental report of one production site (AZM 2001) and are allocated with an economic approach. Thus, impacts of the dairy are allocated to the different products (butter, milk, yoghurt, buttermilk, etc.) based on the production volume and the exchange generated by the respective product. However, the most relevant issue is the amount of milk used for butter production and this has been adjusted with several sources and a sensitivity analysis.

The manufacturing processes for lamination packaging processing are taken from the same source as for the coffee case. These data are rather overestimated (discussed in section 3.4). Furthermore, there were no available data for the lacquer-layer based on nitrocellulose (NC). In this case study the nitrocellulose layer is represented by alkyd paint. Rather pessimistic assumptions are made for losses of the NC-based lacquer and the synthetic wax.

Emissions of refrigerant in transportation systems are based on a rough estimation based on a UK study conducted in 1999 (MarchConsultingGroup 1999). Unfortunately no transport distances for this study are known. Therefore the emissions per ton-kilometre had to be estimated. It cannot be decided whether the effects are over- or underestimated.

4.5 Conclusions

This case study investigated the life cycle of butter consumption. The most relevant factors concerning the environmental impacts from the whole supply chain are for most indicators:

- Butter production,
- spoilage or wastage,
- domestic storage,
- and, in the case of CED and ODP, refrigerated storage and transportation is relevant as well.

As a consequence, the most relevant measures reducing the environmental impacts would be to optimize milk and butter production. It was not part of this study to analyse butter production processes. However, neither the packaging industry nor consumer's behaviour can influence this process.

Another important factor is the reduction of leftovers. A high share of leftovers results in higher impacts. Spoilage in households will only occur when people buy a package of butter which is not eaten within a reasonable time, thus causing the butter to become rancid. In case of 'rare-butter-eaters', small packages will probably avoid spoilage. Regarding small butter packages, the use in hotels or restaurants is more common than in private households. This case has not been investigated in detail (mainly the distribution and selling stage as well as the storage at the hotel will be different). Anyway, in hotels and restaurants wastage is probably higher than in private households because all leftovers are thrown away. The alternative to small packages would be the serving of cut butter pieces on a buffet were the guest could decide how much butter they take. But, also in this case, it is possible that butter is left over, because, on the one hand, guests put more on their plates than they need and, on the other hand, not all butter of the buffet is used, which will then turn into wastage (no use of the butter is allowed for 'next time'). It was not possible to determine which option leads to lower wastage. In contrast, the smaller coffee case packaging will probably not fully avoid wastage, but helps to reduce spoilage.

Consumers can influence impacts of domestic storage by reducing the storing time of butter in the refrigerator and freezer, and by using efficient household appliances. Buying butter only when needed and not for stock in the freezer allows the use of a smaller appliance with less total electricity consumption. With the labelling of household appliances, it is quite simple to buy environmental friendly freezers and refrigerators with low electricity consumption.

In case of commercial and industrial refrigerated storage and transportation, emissions of refrigerant and electricity consumptions for keeping goods cold should be minimized. With the application of hydrocarbons and CO_2 as refrigerants, the share of the distribution and selling process and butter production in case of ODP will decrease even more in future.

The impacts of packaging in the life cycle of butter are small. Even if the butter production industry improves its environmental impacts, their share will always be high because of the indispensable use of milk (see also section 4.2). The relative share of packaging on the impacts could increase if processes in the production chain of butter consumption were optimized, but even in this case it is most probable that the influence of packaging remains quite small.

Another option from the consumers' point of view for reducing the environmental impacts of butter consumption could be to eat less butter. Butter can be substituted with other fat-products, e.g. margarine. These options have not been evaluated in this case study.

5 General Conclusions

It should be the aim of every type of industry to minimize the environmental impacts directly related to their products. This study shows, in the case of packaging industry, that this goal can only be reached if also aspects indirectly influenced by the product are taken into account. Thus, the packaging industry should not only aim to improve its production processes and minimize material use, but also to provide packages whose functionality helps to reduce other more relevant environmental impacts in the life cycle, for example as losses. Depending on the product, tailor-made packaging may help to increase overall resource efficiency. This applies to coffee served in a single serving stick. It was not possible to determine if small packaging for butter does avoid wastage or has any other clear environmental advantage or disadvantage.

While the results of this study are not immediately transferable to other packaging systems or other types of food products, this study shows that the environmental impact from the packaging of the investigated sample products is minor in comparison to the impact from the production of the product, its processing and the consumer behaviour in the use of the product. Additionally, depending on the product, packaging can influence the environmental impact of production, processing and use by reducing waste, spoilage, wastage and over-consumption. The method of LCA is appropriate not only to investigate the relevance, but also concerning the influence of the packaging on the whole life cycle of the product.

The authors want to emphasise that a higher share of the environmental impacts of packaging in the full life cycle can be expected for all products with lower burdens from agricultural production, distribution, storing and cooking. Such products are, for example, mineral water (Jungbluth 2006), for which environmental impacts of packaging are quite relevant.

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7 References

Arena U, Mastellone ML, Perugini F (2003): Life Cycle Assessment of a Plastic Packaging Recycling System. International Journal of Life Cycle Assessment Volume 8, Number 2, INT J LCA 8 (2) 92 - 98 (2003), retrieved from: http://dx.doi.org/10.1065/lca2003.02.106

AZM (2001): Umwelterklärung 2001, Aargauer Zentralmolkerei, Suhr

Büsser S, Steiner R, Jungbluth N (2008): LCA of Packed Food Products: the function of flexible packaging: coffee, spinach and butter, ESU-services Ltd. im Auftrag von Flexible Packaging Europe, Düsseldorf, DE and Uster, CH, retrieved from: http://www.flexpack-europe.org/front_content.php?idcat=170

Coltro L, Mourad AL, Oliviera PAPLV, Baddini JPOA, Kletecke RM (2006): Environmental Profile of Brazilian Green Coffee. Int J LCA 11, 16-21

De Monte M, Padoano E, Pozzetto D (2005): Alternative Coffee Packaging: an Analysis from a Life Cycle Point of View. Journal of Food Engineering 66, 405-411

Diers A, Langowski H-C, Pannkoke K, Hop R (1999): Produkt-Ökobilanz vakuumverpackter Röstkaffee. Fraunhofer-Institut für Verfahrenstechnik und Verpackung, 214 pp.

ecoinvent Centre (2007): ecoinvent data v2.01, ecoinvent reports No. 1-25, Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland, retrieved from: www.ecoinvent.org

EPA (1995): Food and Agricultural Industries, Compilation of Air Pollutant Emission Factors, Volume I (AP42). U.S. Environmental Protection Agency

Faist M (2000): Ressourceneffizienz in der Aktivität Ernähren: Akteurbezogene Stoffflussanalyse. Dissertation Nr. 13884 Thesis, Eidgenössische Technische Hochschule Zürich, Zürich, 145 pp, retrieved from: http://e-collection.ethbib.ethz.ch/show?type=diss&nr=13884

Foster C, Green K, Bleda M, Dewick P, Evans B, Flynn A, Mylan J (2006): Environmental Impacts of Food Production and Consumption: A report to the Department for Environment, Food and Rural Affairs., Manchester Business School, DEFRA, London

Guinée JB, (final editor), Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ, Lindeijer E, Roorda AAH, Weidema BP (2001a): Life cycle assessment; An operational guide to the ISO standards; Parts 1 and 2, Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands, retrieved from: http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html

Guinée JB, (final editor), Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ, Lindeijer E, Roorda AAH, Weidema BP (2001b): Life cycle assessment; An operational guide to the ISO standards; Part 3: Scientific Background, Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands, retrieved from: http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html

Habersatter K, Fecker I, Dall`Acqua S, Fawer M, Fallscheer F, Förster R, Maillefer C, Ménard M, Reusser L, Som C (1998): Ökoinventare für Verpackungen. 250, 2. korrigierte und aktualisierte Auflage, Bundesamt für Umwelt, Wald und Landschaft, Bern, Schweiz

Heap R (2003): 16th Informatory Note on Refrigerating Technologies, Refrigerated Transport: Progress achieved and challenges to be met, retrieved from: http://www.iifiir.org/en/doc/1014.pdf

Heyde M, Kremer M (1999): Recycling and recovery of plastics from packagings in domestic wastes. LCA Documents, 5. Eco-Informa Press, Bayreuth

Hischier R, Althaus H-J, Werner F (2004): Developments in Wood and Packaging Materials Life Cycle Inventories. Int J LCA 10, retrieved from: http://dx.doi.org/10.1065/lca2004.11.181.6

Hischier R (2007): Life Cycle Inventories of Packaging and Graphical Paper. ecoinvent report No. 11, v2.0, EMPA St. Gallen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org

Høgaas-Eide M (2002): Life Cycle Assessment (LCA) of Industrial Milk Production. Ph.D. Thesis, Chalmers, Göteborg, SE

Hunt RG (1974): Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives, Midwest Research Institute for U.S. Environmental Protection Agency, Washington D.C.

Jungbluth N (2000): Umweltfolgen des Nahrungsmittelkonsums: Beurteilung von Produktmerkmalen auf Grundlage einer modularen Ökobilanz. Dissertation Nr. 13499 Thesis, Eidgenössische Technische Hochschule Zürich, Umweltnatur- und Umweltsozialwissenschaften, dissertation.de, Berlin, D, 317 pp, retrieved from: www.jungbluth.de.vu

Jungbluth N, Tietje O, Scholz R (2000): Food Purchases: Impacts from the Consumers' Point of View Investigated with a Modular LCA. Int J LCA 5, 134-142, retrieved from: www.esu-services.ch

Jungbluth N (2006): Vergleich der Umweltbelastungen von Hahnenwasser und Mineralwasser. Gas, Wasser, Abwasser 2006, 215-219, retrieved from: www.esu-services.ch

Jungbluth N, Büsser S, Steiner R (2008): Life cycle inventories of food products: EcoSpold LCI database, ESU-services Ltd., Uster, CH, retrieved from: http://www.esu-services.ch/inventories.htm

Kjer I, Simon KH, Zehr M, Zerger U, Kaspar F, Bossel H, Meier-Ploeger A, Vogtmann H (1994): Landwirtschaft und Ernährung. In: Enquete-Kommission «Schutz der Erdatmosphäre» (Editor), Landwirtschaft - Studienprogramm. Economica Verlag, Bonn

MarchConsultingGroup (1999): UK Emissions of HFCs, PFCs and SF6 and Potential Emission Reduction Options, DETR (Department of the Environment, Transport and the Regions)

Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R, Halberg N (2003): LCA food data base, retrieved from: www.lcafood.dk

Perugini F, Maria Laura Mastellone, Arena U (2005): A Life Cycle Assessment of Mechanical and Feedstock Recycling Options for Management of Plastic Packaging Wastes. Environmental Progress Vol.24, No.2, 137-154

Plinke E, Schonert M, Meckel H, Detzel A, Giegrich J, Fehrenbach H, Ostermayer A, Schorb A, Heinisch J, Luxenhofer K, Schmitz S (2000): Ökobilanz für Getränkeverpackungen II. 37/00, Umweltbundesamt, Berlin, retrieved from: www.umweltbundesamt.de/uba-info-daten/daten/bil.htm

PRé Consultants (2007): SimaPro 7.1, Amersfoort, NL, retrieved from: www.simapro.com

Schmitz S, Oels H-J, Tiedemann A (1995): Ökobilanz für Getränkeverpackungen. 52/95, Umweltbundesamt, Berlin

Schweizer Milchproduzenten S (2007): Butter, retrieved from: http://www.swissmilk.ch/

Steiner R, Faist Emmenegger M, Frischknecht R (2005): Ökobilanz Kombi-Kühlschrank Electrolux ERB3105, Uster, retrieved from: http://web484.login-27.hoststar.ch/files/Kuehlschrank_Graue_Energie_ESU_Bericht_1.0.pdf