LCA study of unconsumed food and the influence of consumer behavior

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ABSTRACT

In light of resource depletion and anthropogenic influences on the greenhouse effect, food waste has garnered increased public interest in recent years. The aim of this study is to analyze the environmental impacts of food waste and to determine to what extent consumers` behavior influences the environmental burden of food consumption in households (hereafter called 'use'). An LCA study of three food products is conducted and addresses the impact categories climate change (GWP100), eutrophication (EP), and acidification (AP). Primary energy demand (PED) is also calculated. For adequate representation of consumer behavior, scenarios based on various consumer types are generated. If consumer acts careless towards the environment, the use stage appears as the main hotspot in the LCA of food products. Moreover, results show that the avoidance of wasting unconsumed food can reduce the environmental impact significantly.

Keywords: food waste, consumer behavior, disposal options, environmental impact

1. Introduction

Food is an essential element of human life. The human body demands high-energy organic compounds to function. Furthermore, food contributes to mental, physiological and social comfort (Baccini and Bader 1996).

In the light of global resource depletion and anthropogenic influences on the greenhouse effect, and as these relate to shortages in developing countries, the environmental effects of food production and consumption as well as the influence of food waste in industrialized countries has gained public attention in recent years (Gustavsson et al. 2011; Thurn 2011). Throwing away edible food affects the environment all along the value chain via production, logistic and disposal processes (FAO 2012). This paper aims to examine the amount and effects of unconsumed food in German households, where "unconsumed food" is defined as food products which were still edible at the time of disposal.

Participant food waste diaries of the EU-project "GreenCook" (GreenCook 2011; Ludwig 2013), which were kept for a period of three months, and a review of scientific literature (Gruber 2013) was used to select three food products for further investigation. A life cycle assessment (LCA) was performed for each food, concentrating on the use stage. Results indicate how consumers can influence the environmental profile of food in the use stage. Food-related activities, such as purchasing, storage, preparation and disposal, are also analyzed via LCA. Finally, the burden on the environment of the whole life cycle of wasted edible food is determined.

2. Methods

This study follows the ISO 14040/44 life cycle assessment (LCA) guidelines (ISO 14040 2006; ISO 14044 2009). The LCA software GaBi 6 and related databases were used for LCA modelling (PE International 1992-2013). Environmental impacts were calculated according to the CML 2001 method. Climate change (GWP100), eutrophication (EP) and acidification (AP) were analyzed. Primary energy demand (PED) was calculated additionally.

2.1. Selection of food

Three food products – potatoes, milk and rice – were selected according to the following criteria: (1) high level of disposal, (2) a clear designation in the household diary, (3) no convenience products or food with unclear composition and (4) staple food without seasonal limitation for consumption. Moreover, the use phase should contain at least one process relevant to the energy demand, e.g. refrigerated storage or required cooking. The selected food items and the amounts wasted per person per year are compiled in Table 1.

Table 1. Selected food and wasted edible amount per person during one year (Ludwig 2013)

Food	Waste amount [kg/person·year]
Potatoes	15.1
Milk	11.6
Rice	3.1

2.2. System boundaries and functional unit

The entire life cycle, from cradle to grave, of potatoes, milk and rice was modelled. Germany is used as the geographical reference, with the exception of the agricultural production and industrial processing of rice: here China was chosen as reference country. The time frame is based on current production conditions and the data used reflects the state of the art. The functional unit (FU) was chosen to be 1 kg food disposed after the use phase.

The system boundary, including all relevant processes such as primary production, industrial processing, wholesale and retail, is displayed in Figure 1 for the three different foods. The following differences occur in the use stage. (1) Potatoes and rice are stored at ambient temperature. (2) In contrast to potatoes and rice, milk requires no energy mix prior to consumption in the use stage. Pasteurized whole milk was chosen and was assumed to be consumed uncooked. Pasteurization is done in the industrial processing stage.

The model also includes the consumption of food via digestion in the human body. Although the consumption of food is not part of the functional unit itself, it was considered as a reference for the environmental impact of different disposal routes. A direct comparison of the environmental impact of consumption and the different disposal options does not take place, because abstention from food consumption is no appropriate solution to reduce the environmental impact. The function of food is to supply the human body with energy rich organic compounds (Baccini and Bader 1996).

The disposal routes for the three foods were chosen according to the data from the household diaries (Ludwig 2013). Milk is mainly disposed of in the sink and is delivered to the wastewater treatment facility of a municipal sewage plant, while potatoes and rice are either disposed of with residual solid waste in waste incineration plants or with biological waste in composting plants. Composting was chosen for geographic reasons instead of fermentation in biogas plants, as it is a more common practice for the disposal of biological waste in Germany (Kern et. al 2010).

Capital goods were included in the background datasets for primary production, waste incineration, wastewater treatment and transportation processes. It was estimated that capital goods have a relatively low environmental impact, due to high mass flows during the life span of the infrastructure. Machines, buildings and infrastructure were excluded from use stage processes and from the composting plant model due to lack of complete and clearly assignable data. Also not taken into consideration were transportation of auxiliary materials, refrigerant emissions from cooling appliances in wholesale and retail as well as dishwashing in households. Food waste besides the use phase was not taken into account due to missing data on the wasted amount of specific food products during agricultural production, industrial processing, wholesale and retail (Kranert et al. 2012).

Allocation problems occur in processes that capture the utilization of various products at the same time. This applies to processes such as the storage of food in wholesale and retail. Mass allocation was conducted by computing the share in quantity of a product. The energy demand for the heating of the warehouse and supermarket and for the refrigerated storage of milk was allocated by mass to each respective food. Transport processes were also allocated by mass.

2.3 Data sources and data quality

Datasets from the GaBi database were used for designing and adjusting the models as far as possible (PE International 1992-2013). Missing data were complemented by scientific literature, with the exception of composting of biological waste, where primary data were collected and a model of a composting plant was built. All data used in the model were in the timeframe 2000 to 2013.

An LCA model developed by Muñoz et al. (2007) describes the biochemical transformation of food in the human body and was used in this study to model digestion processes. For the treatment of wastewater datasets from GaBi database were used (PE International 1992-2013).

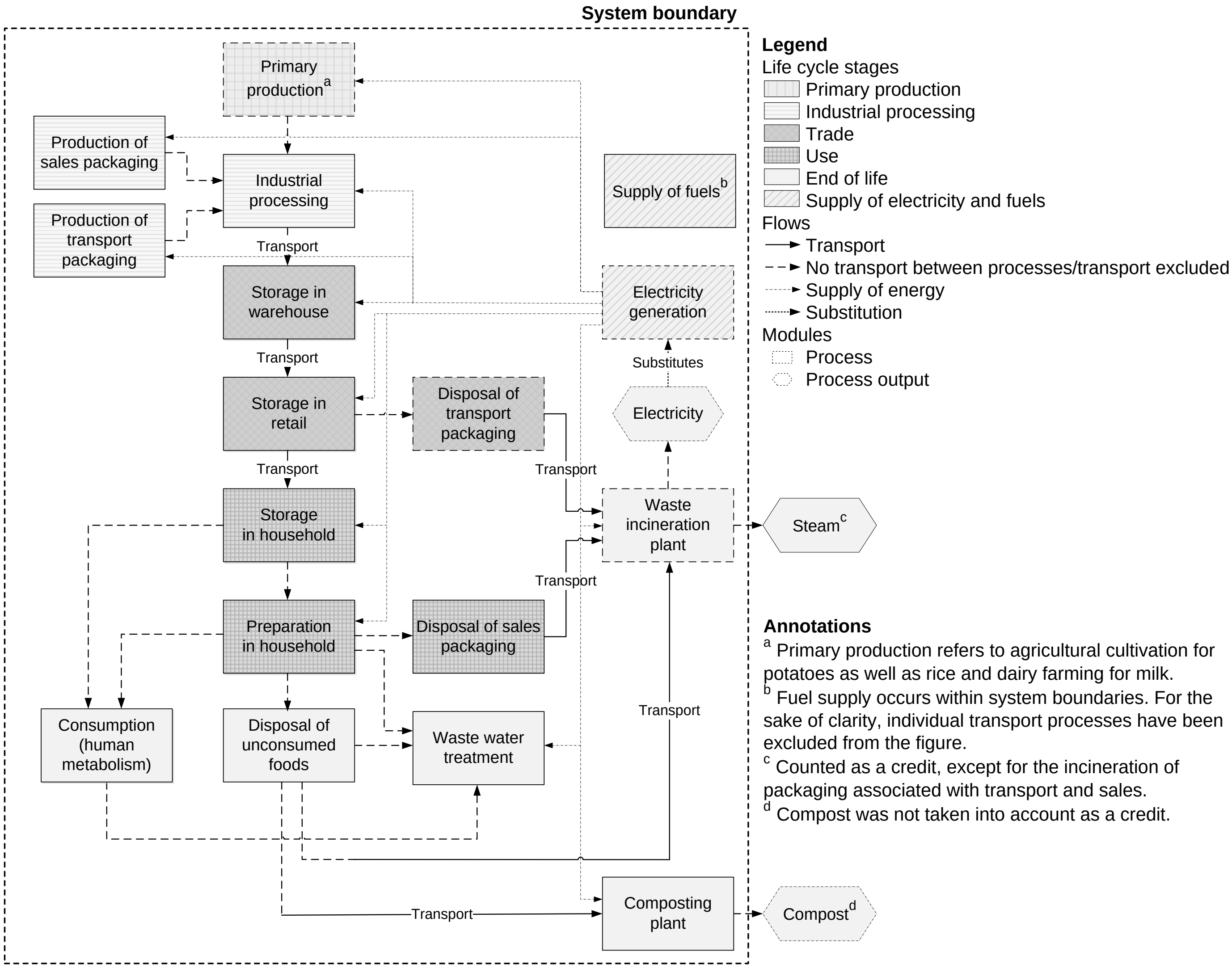

Figure 1. Schematic flow chart of the product system

2.4. Scenario definition

Scenarios based on three different consumer types were generated for adequate representation of consumer behavior during the use phase. (1) The base scenario (base-s) represents the “average consumer”. (2) The “environmental conscious consumer” (conscious-s) acts with ecological awareness due to practicing a lifestyle that minimizes damage to the environment by consciously keeping resource consumption and energy as low as possible. (3) The “careless consumer” (careless-s) remains indifferent to potential environmental impacts of his actions. According to these assumptions, parameters for the purchase, storage, and preparation of the food products were defined. The end-of-life disposal routes for the unconsumed food were set according to the household diaries. In base-s, it was assumed that food is not wasted but consumed. In conscious-s, the food waste was assumed to be separated from the general waste. Unconsumed food is disposed of in the organic waste bin. In careless-s, wasted food is disposed of with the residual solid waste.

2.5. Purchasing

Purchasing is done in the base-s and careless-s cases by car. The distance travelled from household to retail (and return) was set to 10 km according to Tengelmann (2009). In the conscious-s case, where purchasing is not done by a fuel-powered vehicle, the parameter is set to 0 km, because it is assumed that travelling by foot or bicycle has no impact on the environment. Shopping trips combined with other activities, e.g. travelling to work and shopping, were not taken into account as combined trips often lead to longer transport distances. Allocation among the different causes was not possible due to insufficient data.

In base-s and conscious-s, it was assumed that the consumer purchases several products, weighing a total of 10 kg, including the relevant food product. In careless-s it was assumed that consumer is badly organized and only one sales unit of the relevant food is bought. Here it was assumed that base-s and conscious-s plan and organize their shopping trips and purchase can also contain non-food products. Table 2 shows the purchase quantity for the scenarios and the weights of sales units including packaging.

Table 2. Weights of sales units of potatoes, milk and rice

Purchase quantity	**Base-s**	**Conscious-s**	**Careless-s**
Total purchase quantity [kg]			
Scenarios potatoes	10	10	2.51[a]
Scenarios milk	10	10	1.06[b]
Scenarios rice	10	10	1.01[c]
Share of considered food product [%]			
Potatoes	20.51	20.51	100
Milk	10.07	10.07	100
Rice	10.00	10.00	100

[a] 2.50 kg potatoes, weight of sales packaging 0.014 kg ; [b] 1.03 kg milk, weight of sales packaging 0.03 kg; [c] 1.00 kg rice, weight of sales packaging 0.005 kg

2.6. Storage

Potatoes and rice were stored in households at ambient temperature; their storage contributed no environmental burden. The electric energy demand for storage of milk in the refrigerator [MJ/FU] was calculated by a parameterized equation (Eq. 1) based on (Nielsen et al. 2013; Sonesson and Janestad 2003; Geppert 2011). Parameters of Eq. 1 and the data used in the scenarios are listed in Table 3.

Caused by the interaction between consumer and kitchen appliances the electric energy consumption of the refrigerator is increased by about 60 % compared to the operation of a refrigerator under ideal conditions (Defra 2008). Energy losses may result from (1) door of the refrigerator left open too long, (2) irregular defrosting, (3) a dusty heat exchanger, (4) too warm location of the refrigerator, and (5) storage of hot dishes (Utopia AG 2013). Therefore the equation was complemented with the parameter e_K describing these energy losses.

$$E_{KS} = e_K \cdot \left(\left(\frac{E_{Kspez.}}{V_K} \cdot \frac{100}{n} \cdot V_P \cdot t \right) + \left(m_P \cdot c_V \cdot \left(T_A - T_K \right) \right) \right) \qquad \text{Eq. 1}$$

Table 3. Parameter description of Eq. 1 and parameter values used in the scenarios

			Value for scenario		
Parameter	**Description**	**Unit**	**Base-s**	**Conscious-s**	**Careless-s**
e_K	Parameter for interaction between consumer and refrigerator[a]	[-]	1.2	1.0	1.4
$E_{Kspez.}$	Specific electric energy demand of the refrigerator[b]	[MJ/d]	1.5	1.0	2.0
V_K	Capacity[b]	[dm³]	117	117	117
n	Rate of utilization of the capacity[a]	[%]	50	50	50
V_P	Volume of product for storage[c]	[dm³]	1	1	1
t	Duration of storage[d]	[d]	5	2	1
m_P	Mass of product for storage	[kg]	1.07	1.07	1.07
c_V	Specific heat capacity of the product for storage[e]	[MJ/kg·K]	0.00377	0.00377	0.00377
T_A	Temperature of the product at the beginning of storage[f]	[K]	292	292	292
T_K	Average temperature in refrigerator[g]	[K]	278	278	278
E_{KS}	Electric energy demand for the storage of milk	[MJ/FU]	0.56	0.16	1.61

[a] according to (Defra 2008); [b] based on (Siemens-Electrogeräte GmbH 2013); [c] calculated volume of one sales unit of milk, density of milk 1.03 kg/dm³ (Töpel 2004); [d] according to (FrieslandCampina 2013); [e] according to (Töpel 2004); [f] assumed to be ambient temperature; [g] according to (Utopia AG 2013)

2.7. Preparation

Potatoes and rice have to be cooked before consumption. Electric energy demand for cooking was calculated in the model based on (Oberascher et al. 2011) who analyzed cooking of potatoes in two different ways. (1) In the ideal case the potatoes were cooked in a pot with closed lid on the highest power setting of the stove up to the boiling point. Then, the heat was reduced. (2) In the non-ideal case the pot is not covered with a lid. The highest heat setting is chosen and not reduced after reaching the boiling point. The ideal case was taken as a basis for conscious-s, the careless-s is modelled after the non-ideal case and a calculated average of the two cases was set as base-s. The electric energy demand for cooking of potatoes and rice was considered to be equal (Table 4).

Table 4. Demand of electric energy for cooking of 1 kg potatoes or rice (Oberascher et al. 2011)

Scenario	**Electric energy demand [MJ]**
Base scenario (base-s)	1.4
Environmental conscious scenario (conscious-s)	0.7
Careless scenario (careless-s)	2.1

2.8. Disposal routes

After storage and if it is necessary preparation, the food is disposed. The disposal routes were set according to the household diaries and listed in Table 5 with the different scenarios. The model of the composting plant was built based on primary data from the German composting plant Kirchheim unter Teck (Kompostwerk Kirchheim unter Teck 2013).

Table 5. Disposal routes for the scenarios of potatoes, milk and rice (Ludwig 2013)

Scenario	**Potatoes**	**Milk**	**Rice**
Base scenario (base-s)	Consumption	Consumption	Consumption
Environmental conscious scenario (conscious-s)	Composting	Consumption	Composting
Careless scenario (careless-s)	Waste incineration	Sink/Waste water treatment	Waste incineration

3. Results

In Table 6 the results per functional unit (FU) of the LCA of potatoes are listed. The results of the use stage are displayed as a total and in detail for purchasing, preparation and the disposal of the sales packing via waste incineration. Results of the life cycle stages primary production and retail trade were similar for all scenarios, since the same assumptions were made in the model. Primary production and industrial processing (datasets out of the GaBi database by PE International 1992-2013) were summarized in the following to simplify matters and hereinafter called production. Retail trade was modelled in a similar way for potatoes, milk and rice. There were no differences assumed for primary production and retail trade for the different scenarios, thus the results were identical.

Table 6. Results per functional unit (FU) for LCA of potatoes

Life cycle impact assessment categories	Production[a]	Retail trade	Purchasing	Preparation	Disposal of sales packaging	Use (total)	End of life
GWP [kg CO_2-eq/FU]							
Base-s	0.059	0.029	0.174	0.206	0.014	0.394	0.473[b]
Conscious-s	0.059	0.029	0.000	0.094	0.014	0.109	0.480[c]
Careless-s	0.059	0.029	0.692	0.315	0.014	1.021	0.555[d]
EP [g PO_4^{3-}-eq/FU]							
Base-s	0.021	0.010	0.074	0.041	0.000	0.116	0.197[b]
Conscious-s	0.021	0.010	0.000	0.020	0.000	0.020	0.051[c]
Careless-s	0.021	0.010	0.295	0.062	0.000	0.357	0.045[d]
AP [g SO_2-eq/FU]							
Base-s	0.126	0.059	0.374	0.347	0.004	0.725	0.227[b]
Conscious-s	0.126	0.059	0.000	0.159	0.004	0.162	0.261[c]
Careless-s	0.126	0.059	1.489	0.531	0.004	2.023	0.061[d]
PED [MJ/FU]							
Base-s	1.330	0.406	2.587	3.623	0.009	6.220	1.035[b]
Conscious-s	1.330	0.406	0.000	1.649	0.009	1.658	1.253[c]
Careless-s	1.330	0.406	10.292	5.548	0.009	15.850	-4.770[d]

[a] includes primary production and industrial processing; [b] consumption; [c] composting; [d] waste incineration

The use and end-of-life stages of base-s dominate all considered impact categories and have the highest PED. In the conscious-s case, the main contributor is the end of life; in case of careless-s the use stage has the highest environmental impact. The negative value for PED (-4.770 MJ/FU) of careless-s is due to a credit of -5.599 MJ/FU for the generation of electric energy and steam from the incineration of waste. In the use stage, the purchase of food contributes the highest environmental impact in the base scenario as well as in careless-s. During fuel combustion, CO_2 and volatile organic compounds (VOCs) were emitted. These emissions result in a GWP for purchasing of 0.692 kg CO_2-eq/FU in careless-s and 0.174 kg CO_2-eq/FU in base-s. No environmental impact was associated with purchasing of conscious-s. The environmental impact of end of life scenarios were not compared to base-s, because of the function of food (see section 2.2).

Table 7 shows the results per FU of the LCA of milk in this study. The use stage is presented in detail for purchasing, storage and the disposal of the sales packaging via waste incineration. In contrast to the results of potatoes, the production is the main contributor to all impact categories and has the highest PED (32.8 MJ/FU) in all scenarios. In careless-s the use stage dominates the environmental burden. The purchase of milk has the highest environmental impact in the use stage of careless-s. The environmental impact of the storage of the milk is lower than of the purchase. With a GWP of 0.031 kg CO_2-eq/FU the disposal of the sales packaging is similar to the storage of milk in base-s with 0.032 kg CO_2-eq/FU. In conscious-s the GWP of the storage (0.009 kg CO2-eq/FU) is even 29 % lower. The contribution to the EP with 0.203 g PO_4^{3-}-eq/FU is for the consumption significantly higher than for the disposal of milk with 0.008 g PO_4^{3-}-eq/FU. This is caused by a greater amount of organically loaded wastewater resulting from consumption.

Table 7. Results per functional unit (FU) for LCA of milk

Life cycle impact assessment categories	Production[a]	Retail trade	Purchasing	Storage	Disposal of sales packaging	Use (total)	End of life
GWP [kg CO_2-eq/FU]							
Base-s	0.842	0.026	0.178	0.032	0.031	0.241	0.360[b]
Conscious-s	0.842	0.026	0.000	0.009	0.031	0.041	0.360[b]
Careless-s	0.842	0.026	1.665	0.091	0.031	1.788	0.006[c]
EP [g PO_4^{3-}-eq/FU]							
Base-s	0.357	0.009	0.076	0.006	0.003	0.085	0.203[b]
Conscious-s	0.357	0.009	0.000	0.002	0.003	0.005	0.203[b]
Careless-s	0.357	0.009	0.709	0.017	0.003	0.730	0.008[c]
AP [g SO_2-eq/FU]							
Base-s	1.361	0.043	0.383	0.053	0.021	0.457	0.235[b]
Conscious-s	1.361	0.043	0.000	0.016	0.021	0.036	0.235[b]
Careless-s	1.361	0.043	3.583	0.154	0.021	3.757	0.009[c]
PED [MJ/FU]							
Base-s	32.808	0.230	2.650	0.560	0.107	3.317	1.071[b]
Conscious-s	32.808	0.230	0.000	0.164	0.107	0.270	1.071[b]
Careless-s	32.808	0.230	24.769	1.613	0.107	26.489	0.040[c]

[a] includes primary production and industrial processing; [b] consumption; [c] waste water treatment

In Table 8 the results of the LCA per FU of rice are listed. The results of the use stage are displayed in detail for purchasing, preparation and disposal of the sales packaging via waste incineration. Production of base-s has an EP of 0.278 g PO_4^{3-}-eq/FU and AP of 2.623 g SO_2-eq/FU. In careless-s the use phase is the main contributor to all impact categories. Similar to the potato PED results, rice has a negative value for end of life, due to a credit of -5.599 MJ/FU for the generation of electricity and steam from the incineration of waste. In the use stage of careless-s, purchasing of rice dominates all impact categories and the PED with 6.398 MJ/FU, respectively. A closer look on the end of life shows that GWP of the disposal option composting (conscious-s) and of consumption (base-s) is similar with 0.480 kg CO_2-eq/FU and 0.602 kg CO_2-eq/FU, respectively, since both processes describe the biological degradation of organic compounds.

Table 8. Results per functional unit (FU) for LCA of rice

Life cycle impact assessment categories	Production[a]	Retail trade	Purchasing	Preparation	Disposal of sales packaging	Use (total)	End of life
GWP [kg CO_2-eq/FU]							
Base-s	0.152	0.089	0.182	0.215	0.043	0.440	0.602[b]
Conscious-s	0.152	0.089	0.000	0.103	0.043	0.146	0.480[c]
Careless-s	0.152	0.089	1.730	0.324	0.043	2.097	0.555[d]
EP [g PO_4^{3-}-eq/FU]							
Base-s	0.278	0.022	0.077	0.055	0.005	0.137	0.185[b]
Conscious-s	0.278	0.022	0.000	0.034	0.005	0.039	0.051[c]
Careless-s	0.278	0.022	0.737	0.076	0.005	0.817	0.045[d]
AP [g SO_2-eq/FU]							
Base-s	2.623	0.162	0.391	0.359	0.024	0.773	0.214[b]
Conscious-s	2.623	0.162	0.000	0.170	0.024	0.194	0.261[c]
Careless-s	2.623	0.162	3.722	0.542	0.024	4.288	0.061[d]
PED [MJ/FU]							
Base-s	2.346	1.470	2.702	3.646	0.041	6.389	0.976[b]
Conscious-s	2.346	1.470	0.000	1.671	0.041	1.713	1.253[c]
Careless-s	2.346	1.470	25.731	5.571	0.041	31.343	-4.770[d]

[a] includes primary production and industrial processing; [b] consumption; [c] composting; [d] waste incineration

Table 9 shows an extrapolation of the LCA results for the annual consumption per capita in Germany. LCA results of base-s were takenfor production, retail trade and the use stage.. For unconsumed potatoes and rice, a combination of the disposal options composting and waste incineration was created. Milk is only disposed via sink. The amount of unconsumed food is taken from Table 1. In the case of the consumed food results of base-s were taken for the end of life. According to the German Statistisches Bundesamt (2012), 56.6 kg potatoes, 101.3 kg fresh milk products and 5.4 kg rice were consumed per capita in 2012. No data was available for consumed milk, therefore the amount of fresh milk products was used.

Through avoidance of waste from unconsumed potatoes, a general consumer can reduce GWP by approximately 22 %, EP by 13 %, AP by 20 % and PED by 16 %, respectively. In the case of milk, GWP, EP, AP and PED can be reduced by approximately 10 %. Avoiding unconsumed rice waste reduces emissions and PED by 30-37 %. Table 9 illustrates the avoided environmental impacts, as compared with the environmental impacts of a diesel-powered car. Considering a family of five, the avoided GWP of unconsumed potatoes corresponds to a route halfway across Germany (approximately 500 km). The GWP resulting from unconsumed milk is equivalent to about 440 km and the GWP of unconsumed rice corresponds to about 120 km.

Table 9. Extrapolation of LCA results to the annual consumption per capita in Germany (Statistisches Bundesamt 2012; Ludwig 2013)

Food product	**GWP [kg CO_2-eq/FU]**	**EP [g PO_4^{3-}-eq/FU]**	**AP [g SO_2-eq/FU]**	**PED [MJ/FU]**
Potatoes				
Unconsumed (wasted edible food)[a]	15.12	2.95	16.21	93.78
Consumed	54.02	19.45	64.39	508.89
Milk				
Unconsumed (wasted edible food)[a]	12.89	5.31	21.62	420.86
Consumed[b]	148.81	66.25	212.32	3791.25
Rice				
Unconsumed (wasted edible food)[a]	3.56	1.50	11.70	35.10
Consumed	6.92	3.36	20.37	60.38

[a] savings potential of avoiding unconsumed food; [b] annual consumption of fresh milk products per capita in Germany

4. Discussion

The results of this LCA study are hardly comparable to previous studies. Differences from previous studies include different system boundaries and levels of detail for examination of the life cycle stages as well as the representation of consumer behavior in the model. The consumer modelling included four parameters: (1) distance travelled for purchasing, (2) purchased amount of food products, (3) storage and preparation of food in households and (4) amount of unconsumed food in households. An evaluation of 36 LCA studies of food products, which can be found in Gruber (2013), showed that no general conclusions can be drawn as to which life cycle stage of different food products is most important as the level and type of environmental impact from individual life cycle stages varies according to the considered food product. In the current study, however, the most important factor influencing environmental impact is consumer behavior as identified by the authors. This is clearly seen when looking at the results of the different scenarios of the highly-processed staple products milk and rice. Depending on how the consumer behaves during the use stage, the primary production including the industrial processing or the use stage dominates the environmental impacts and the PED.

Modelling assumptions and estimations were based on literature data, which must be critically examined. Therefore, this study has some limitations. First of all, data gaps on the food losses of individual food products during the whole life cycle exist, as this is a seldom examined issue in LCA and the collection of this data requires much effort. The end-of-life inventory data for the waste incineration plant and the municipal wastewater treatment plant could are not adjusted for the input of a specific food product. In the case of waste incineration, the process describes an incineration of mixed municipal solid waste. The input flow of the waste water treatment plant is polluted municipal sewage water. Neither process reflects the specific composition of the emissions related to the disposal of the individual food products. The LCA model of the composting plant describes the composting of mixed organic waste and therefore also does not reflect the specific emissions of the disposal of individual food products. Due to this insufficient data availability, the comparability of the disposal options in this study is limited.

Despite the limitations of the statement of this study regarding the end of life, there is no doubt that the environmental impact can be significantly reduced if the amount of wasted unconsumed food decreases. Additionally, the environmental impact can be significantly decreased in the use stage by an environmentally conscious consumer. Purchasing has the highest effect on the evaluated impact categories and on the PED. The reason for this is the fuel consumption with its related release of emissions. The mass-based allocation of purchased food products transported by car must be examined. For example, the transport of 20 kg of products by car does not require significantly more fuel than the transport of 1 kg of products. Nevertheless, in light of the goal and scope of this study it makes sense to assign the environmental impact to consumers' behavior. The purchase of several items in one shopping trip saves additional trips and related fuel, and thereby reduces the environmental impact. Additionally, consumers can reduce the resulting emissions by decreasing the electric energy demand, particularly where food storage is concerned. For example, consumers can take the following measures: (1) select a refrigerator with a high energy efficiency class, (2) use a refrigerator of the appropriate size and use it often, (3) only open the refrigerator when necessary, (4) do not store warm dishes in the refrigerator, (5) defrost regularly, (6) situate the refrigerator in a cool location, (7) set the temperature to an optimal setting (about 7 °C) and (8) clean the heat exchanger on a regular basis. Furthermore, an energy-conscious handling of kitchen appliances while cooking reduces the overall environmental impact of the use stage. The consumer can decrease the electric energy demand for cooking by covering the pot with a lid and reducing the heat setting of the stove. Since each food processing step requires resources and leads to the release of emissions, consumers can significantly decrease the environmental impact of food by avoiding food waste in terms of unconsumed and also potentially energy-intensive prepared food.

When evaluating the environmental impacts from cradle to grave of food products, it has to be taken into account that food supplies the energy required by the human body and delivers many health benefits beyond energy and nutrition (Roy et al. 2009). Considering the results of this study, it may seem that stopping or minimizing food consumption would be the easiest way to reduce the associated environmental impacts. However, given that the function of food is to provide energy for the human body, eliminating consumption is not a reasonable possibility. Therefore, it is not appropriate to compare the metabolic-based emissions of the consumption with the disposal of food products, even though the human body has been found to be an important source of emissions in GWP and EP (Muñoz et al. 2007) and therefore should be included when identifying the life-cycle hotspots of a food product. In this study the consideration of consumption was necessary because the overall environmental impact of food consumption was assessed, taking into account both the consumed and unconsumed amount of each individual food product.

5. Conclusion

Results of this study show that measures for reducing the environmental impact of food consumption must take place at different levels. One of these levels is the life-cycle use stage, as here the consumer can decide the most efficient way to reduce associated emissions. Emissions from the use stage can be reduced by environmentally responsible consumer behavior. Together, the prevention of waste in terms of unconsumed food can significantly decrease the impact on the environment.

Due to a lack of understanding and awareness of environmental issues, the average consumer often misses opportunities for beneficial environmental behavior (Vázquez-Rowe et al. 2013). Through projects and educational campaigns such as "GreenCook" (GreenCook 2011) attempts are being made to encourage consumers to think and act proactively.

The influence of consumer behavior on the LCA results has been found to be important. The life-cycle use stage of food products should not be overlooked in LCA studies. It is important to include food waste in the entire environmental assessment and not only in the use phase. Further research must be conducted to represent consumer behavior more accurately in LCA. To enable comparison among results, the LCA community needs to develop a common method for modelling consumer behavior. Moreover, end-of-life data is required for modelling waste disposal emissions in more detail.

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