Environmental impacts of German food consumption and food losses

Ulrike Eberle[1,*], Jacob Fels[2]

[1] corsus-corporate sustainability, Dr. Ulrike Eberle, Nernstweg 32-34, D-22765 Hamburg
[2] Universität Witten-Herdecke, Zentrum für Nachhaltige Unternehmensführung, Alfred-Herrhausen-Str. 1, 58448 Witten
[*] Corresponding author. E-mail: *u.eberle@corsus.de*

ABSTRACT

Objective was to assess the environmental burden of food consumption and food losses in Germany with the aim to define measures to reduce environmentally relevant food losses. The assessment is based on a Screening Life Cycle Assessment and carried out from a consumer's perspective. Data have been taken from the German income and consumption sample and German production and trade statistics. In order to model the food baskets and its product chains some simplifications had to be done. The analysis shows that German food consumption emits 2.7 tons of greenhouse gases per person each year. 14 cubic meters of blue water are used for agricultural food production per person, and 2673 square meters of agricultural land are occupied each year per German for food consumption. In particular animal products cause high environmental burdens. Losses along the product chains have a share between 13 and 20 percent in environmental impacts.

Keywords: Screening Life Cycle Assessment, food consumption and losses, environmental impacts of German food basket, national origin of water and land use

1. Introduction

In recent years food waste is more and more of public interest. 2011 the documentary "Taste the Waste" came to German cinemas and its alarming message ("half of the food is spoiled") caused disgust about our way to deal with food in the public. In 2011 also the Food and Agricultural Organization (FAO) published a study on global food waste with the result that about one third of the food produced at global level is spoiled. This corresponds to 1.3 billion tons per year (Gustavsson et al. 2011). At the same time according estimations of the FAO 925 million people were starving.[1] Also in Germany a study on food waste was carried out on behalf of the Federal German Agricultural Ministry (BMELV). This study came to the result, that each year each German wastes 82kg food (Kranert et al. 2012).

In this context this study was carried out as part of a project aiming to reduce food waste in Germany on behalf of the Federal German Environmental Agency (Jepsen&Eberle 2014).

Aim of this part presented here was to assess the environmental burden of food consumption and food losses in Germany along the whole life cycle.

2. Methods

The assessment of German environmental impacts due to food consumption and food losses is based on a screening Life Cycle Assessment. Reference year is 2010.

The calculation is carried out from a consumer's perspective, meaning that the study starts from the consumer's food consumption (in-house and out-of-home) and analyzes every step of the various product chains. Drinks and candies haven't been considered. At the starting point the analysis differentiates between private consumers' food basket (in-house consumption) and the food basket of large scale consumers such as restaurants, and canteens (out-of-home consumption). Starting from in-house and out-of-home consumption the product chains are analyzed downstream as far as agricultural production. This includes storing and cooking in households respectively in canteens and restaurants, the shopping trip respectively food transportation to large scale consumers, retail and wholesale, food processing, agricultural production and all kind of transports along the products' life cycles. In order to provide information on the relevance and concrete impacts of food waste, environmental burdens are allocated to consumed and spoiled food on every step of the product chain. But for meat where food

[1] http://www.fao.org/mdg/goalone/en/; Status: 8. August 2012

losses due to slaughter by-products have been considered separately, all other food losses have been considered in the study without distinguishing between avoidable and unavoidable losses. [2]

2.1. System boundaries and modelling

The model was divided in four life cycle phases: agricultural production, food processing, retailing, and consumption.

System boundaries were set as follows:

For agricultural production energy, land, pesticide, fertilizers and water use for irrigation for production of plant products for direct human consumption but also for livestock feed have been taken into account. Land use and water consumption have only been taken into account in this life cycle stage. For livestock's breeding feed consumption, transports of feed and energy use were considered as well as direct emissions. Furthermore the necessary transports to food processing have been included within this life cycle phase.

For food processing energy use and direct emissions for all kinds of food processing like slaughtering, milling, baking, and processing of dairy products have been considered as have the transports to retail.

For retailing (wholesalers and/or retailers) energy use and freezing agent losses have been considered. Regarding in-house consumption also transports between wholesalers and retailers have been taken into account. Regarding out-of-home consumption transports from the wholesaler to the place of out-of-home consumption have been included.

For in-house consumption energy use for the shopping trip, the storing of purchased food, and cooking have been respected. For out-of-home consumption energy use for preparing of meals, food storing and air conditioning of restaurants have been taken into account; trips to the restaurant have been excluded. Customer transport to the place of out-of-home consumption has not been considered.

However, the production of seeds, water use outside agricultural production, all kind of packaging, and waste treatment haven't been considered within this study.

Modelling and the calculation itself were done with the software Umberto NXT LCA.

2.2. Data

Data for the composition of the two food baskets analyzed have been taken from statistical data such as the German income and consumption sample (Statistisches Bundesamt 2011) and German production and trade statistics (BMELV 2013). Also data from previous projects assessing the environmental impacts of German food consumption (Eberle et al. 2006, Wiegmann et al. 2005) have been used for this purpose.

Data for food losses have been used from two German studies carried out recently (Kranert et al. 2012, Peter et al. 2013) and from a study on behalf of the Food and Agricultural Organization (FAO) (Gustavsson et al. 2011).

Figure 1 and 2 show the material flows used as basis for the calculation of the environmental impacts of German food consumption.

Furthermore to calculate impacts it had to be estimated which share in the products was consumed cooked and which without cooking.

Most generic environmental data needed like electricity grids, transports, pesticides, and fertilizers have been taken from ecoinvent 3.01 database. Input and output data for agricultural production (including methane and nitrous oxide emissions from soils and animal production), food processing and retail have been taken from GEMIS 4.81 database. An exception has been made for water consumption data which are not included in GEMIS. These have been used from a study carried out by Mekkonen and Hoekstra (2010). In the study only data for the so called 'blue water' have been used.

To have the possibility to analyze where water consumption and land use is highest due to German food consumption and food losses, water consumption and land use in agricultural production were correlated with their national origins.

[2] This was done due to the reason that the characteristics 'avoidable' or 'unavoidable' are closely correlated with a value system that can change in the course of time.

Figure 1. Material flows of in-house food consumption and food losses per person and year (number format: 0,2 = 0.2). Data are given in ‘consumption’ weight (e.g. boneless meat and w/o slaughter by-products).

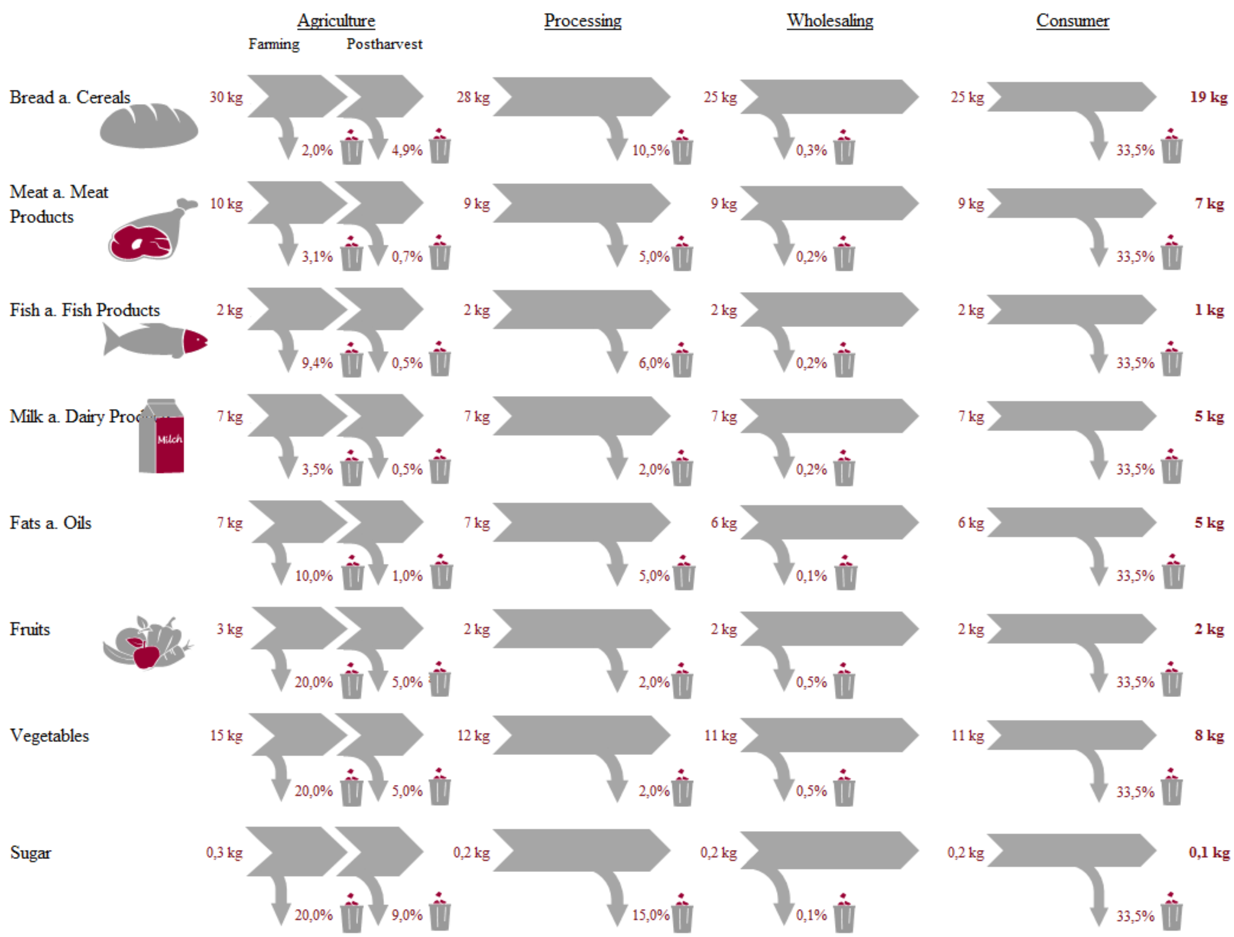

Figure 2. Material flows of out-of-home food consumption and food losses per person and year (number format: 0,2 = 0.2). Data are given in 'consumption' weight (e.g. boneless meat and w/o slaughter-by products).

2.3. Simplifications and assumptions

In order to model the food baskets and its product chains some simplifications had to be done. Main reason for that was the lack of statistic and/or consistent environmental data, but also for modeling reasons (reduction of complexity of food production and distribution chains). The following simplifications have been made:

All food imports are modelled on agricultural level, thus also all food processing takes place in Germany. This simplification was done because statistical data don't show at which stage of the product's life cycle it is imported and also input/output data for processing in all the countries needed are not available.

Furthermore it was assumed that production of fodder components is done like in Germany with the same import countries and import shares for each fodder component. This simplification has to be done due to two reasons: one is the actual restrictions of the software program (which will be hopefully solved in next time); the other that import data for fodder components could not be looked into within this project. The composition of the livestock feed was modelled with respect to country specific data of the country where livestock breeding takes place.

Regarding poultry the assumption was made, that all meat is produced from broilers, the share of laying hens meat was not considered.

In addition, it was assumed that all food imports from overseas are carried out only by ship. This simplification was done with respect to the very low relevance of air freight transports of food to Germany which is about 0.12% of all food imports (Keller 2010).

Moreover, organic production systems are not included also due to their low relevance – only 6% of the agricultural land in Germany is cultivated regarding standards for organic production (BLE 2012) – and due to the fact that not all data needed have been available for organic production.

Besides, it was assumed that households buy all their food at retailers, purchases direct at the farm or at local markets haven't been considered. For out-of-home consumption it was assumed that all food is delivered by wholesalers.

2.4. Allocations

Most agricultural production systems have more than one output. Milk cows, for example are kept for milk as main product and meat as co-product. In LCAs environmental burdens need to be allocated to the products by different allocation methods (mass, economic, or commodity specific allocations). In order to reduce the complexity of the model and due to some data lacks allocations have been made only regarding food losses, where a mass allocation was applied at all life cycle stages. In case of meat a physical allocation was done to allocate burdens to meat and slaughter by-products. An economic allocation was renounced because prices in particular regarding by-products vary enormously with respect to time and geographical origin. Thus, regarding milk cow keeping an economic allocation was made with the result that 80% of impacts have been allocated to milk.[3] Also with respect to dairy production allocations have been made. Here an allocation with respect to milk solids was chosen, which is regarded as 'fairest' allocation method for dairy products (Lundie et al. 2007). Regarding the production of soy and rapeseed shred material flows have been allocated to oil and shred regarding their heating value equivalents, which was the approach chosen in the database used. In all other cases of agricultural production 100% product allocation was chosen. This approach leads to a slight overestimation of environmental burdens in agriculture.

In case of combined power generation burdens were allocated in relation to energy yield.

2.5. Impact assessment

The impact assessment methodology used is ReCiPe Midpoint (Goedkoop et al. 2008). The following environmental impact categories have been assessed: climate change, fossil depletion, freshwater eutrophication, marine eutrophication, metal depletion, ozone depletion, particulate matter formation, photochemical oxidant formation, and terrestrial acidification. Furthermore also the use of agricultural land and agricultural water use for food production have been analyzed. Toxicity indicators have not been assessed mainly because the input data for pesticide use available for the different foods have been very unspecific.

3. Results

The analysis shows that German food consumption emits 2.7 tons of greenhouse gases per person each year. 14 cubic meters of blue water are used for agricultural food production per person, and 2673 square meters of agricultural land are occupied each year for each German for food consumption. Table 1 shows total results for each indicator according to life cycle phases.

The results show that agricultural production and consumption are responsible for the main impacts of German food consumption and food losses. For all indicators analyzed these two life cycle phases cause more than 87 percent of the environmental burden. In contrast food processing and retailing have for all indicators and inventory parameters less environmental impact.

GWP-100, fossil depletion, freshwater and marine eutrophication, metal depletion and terrestrial acidification are mainly caused by energy use along the products' life cycles and in particular GWP-100 also by emissions directly from agricultural production. Particulate matter formation and photochemical oxidant formation originate mainly from transport emissions.

The biggest part of the impacts is caused by in-house consumption (61-80% for each indicator) which has also the highest share in amounts. Food losses due to in-house food consumption have a share in the total environmental burden between 8 and 14 percent, out-of-home food consumption 6 to 19 percent, and food losses due

[3] The remaining 20% have been allocated to mother cow meat, but haven't been considered further in the model.

to out-of-home consumption between 2 to 9 percent. Total losses have a share of 15 to 21 percent. Figure 3 shows the shares in in-house and out-of-home food consumption and food losses regarding environmental burdens of the different indicators and inventory parameters.

Regarding the consumed respectively wasted products results show that animal products like meat and dairy products cause most of the environmental burden of food consumption and food losses, although the share of plant products is higher regarding amounts of consumption or waste. This is the case for all analyzed impact indicators. Only regarding agricultural water use, plant products consume more water in total and per kilogram product (Table 2, Table 4).

Table 1. LCA results for life cycle phases and in total per person and year

Impact categories	Unit	Agriculture	Processing	Retailing	Consumption	Total
GWP-100a	kg CO2e	1.56E+03	1.19E+02	5.81E+01	1.02E+03	2.75E+03
Fossil depletion	kg oil-equiv.	2.69E+02	2.56E+01	1.51E+01	4.50E+02	7.59E+02
Freshwater eutrophication	kg P-equiv.	1.64E-01	8.16E-02	5.45E-02	7.33E-01	1.03E+00
Marine eutrophication	kg N-equiv.	9.25E-01	1.57E-01	1.44E-02	2.09E-01	1.31E+00
Metal depletion	kg Fe-equiv.	2.23E+01	1.13E+00	1.00E+00	4.51E+01	6.96E+01
Ozone depletion	kg CFC-11-equiv.	5.90E-05	5.72E-06	3.20E-06	1.25E-04	1.93E-04
Particulate matter formation	kg PM-10-equiv.	2.60E+00	6.81E-02	3.13E-02	9.79E-01	3.68E+00
Photochemical oxidant formation	kg NMVOC	9.66E+00	4.19E+00	3.79E+00	4.51E+01	6.27E+01
Terrestrial acidification	kg SO2-equiv.	1.48E+01	2.00E-01	8.09E-02	2.58E+00	1.76E+01
Agricultural land use	m²*a	2.67E+03	0.00E+00	0.00E+00	0.00E+00	2.67E+03
Agricultural water use	L	1.40E+04	0.00E+00	0.00E+00	0.00E+00	1.40E+04

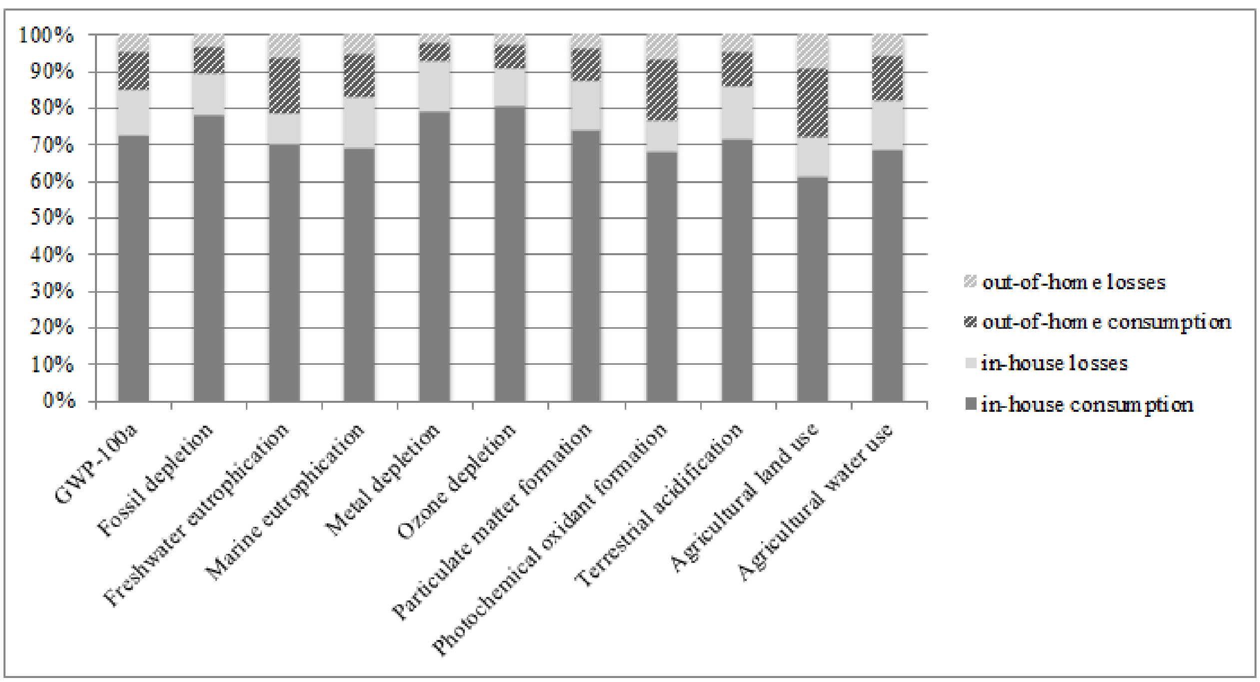

Figure 3. Shares of in-house and out-of-home food consumption and food losses regarding environmental burdens caused by German food consumption

Results per kg product (Table 2) show that animal products in the German food basket have a higher impact for all analyzed impact categories and parameters than have plant products in the German food basket. The only exception is water use. In particular in the case of agricultural land use for food production this is obvious: for the production of animal products eight times more land is needed per kilogram food than for plant products.Also with respect to the indicator terrestrial acidification differences are significant: the impact per kg consumed animal based food is nine times higher than that of products with a plant based origin. Also for marine eutrophication (six times higher), particulate matter formation (five times higher), and global warming (four times higher) the differences are similar. For all other indicators the impact of animal products is between 1.7 and 4.7 times higher than that of plant products. Only for agricultural water use (irrigation water) for food production the water use of animal products is lower as for plant products.

Results show that in total most water for German food consumption and losses is used in Germany (23%) followed by Spain (18%) and Pakistan (17%). Results for animal products show that also Germany is responsible for most of the water use (77%) followed by France (11%) and Argentina (8%). In contrast regarding plant based food most water is used in Spain (23%) followed by Pakistan (23%) and the US (9%).

Regarding land use most agricultural land is used in Germany (73%). This is also the case for animal (70%) and plant based food (75%). Germany is followed by Argentina and Brazil (both 9%). This is the same for animal-based products but not for plant-based products where the next highest shares have the Netherlands and the Czech Republic with 5 percent.

Table 3 shows the additional environmental impacts which are caused per kilogram consumed food due to food losses. These are much higher for out-of-home consumption than for in-house consumption[4]. This is mainly due to the fact that losses at out-of-home consumption are much higher than for in-house consumption but also for the differences in the composition of the consumed food. Thus, the high value for per kilogram consumed food for water use is mainly due to the fact that at out-of-home consumption regarding our data much more rice is consumed and spoiled than at in-house consumption. The value for land use is so much higher because of the higher share of waste but also due to the higher consumption and in consequence losses of meat.

Table 2. Average impact for German food consumption and losses per kg product

Impact categories		**Animal products**	**Plant products**
GWP-100a	kg CO2e	9.21	2.55
Fossil depletion	kg oil-equiv.	2.10	1.00
Freshwater eutrophication	kg P-equiv.	2.78	1.41
Marine eutrophication	kg N-equiv.	4.92	0.85
Metal depletion	kg Fe-equiv.	1.74	1.04
Ozone depletion	kg CFC-11-equiv.	0.53	0.26
Particulate matter formation	kg PM-10-equiv.	1.32	0.28
Photochemical oxidant formation	kg NMVOC	1.69	0.86
Terrestrial acidification	kg SO2-equiv.	7.15	0.80
Agricultural land use	m²*a	10.66	1.34
Agricultural water use	l	1.89	3.17

[4] Blumenthal&Göbel (2014) found out that in German communal feeding food losses add to 8 to 30 percent of food consumption in this sector. According to our data the share in food losses is 33.5 percent in out of home consumption (see fig. 2).

Table 3. Additional environmental impacts due to food losses per kg consumed food

Impact categories		in-house consumption	out-of home consumption	total consumption
GWP-100a	kg CO2e	0.9	2.8	1.1
Fossil depletion	kg oil-equiv.	0.2	0.6	0.3
Freshwater eutrophication	kg P-equiv.	2.3E-04	1.4E-03	3.6E-04
Marine eutrophication	kg N-equiv.	4.8E-04	1.5E-03	6.0E-04
Metal depletion	kg Fe-equiv.	2.5E-02	3.6E-02	2.6E-02
Ozone depletion	kg CFC-11-equiv.	5.2E-08	1.2E-07	6.0E-08
Particulate matter formation	kg PM-10-equiv.	1.3E-03	3.2E-03	1.5E-03
Photochemical oxidant formation	kg NMVOC	1.3E-02	9.4E-02	2.2E-02
Terrestrial acidification	kg SO2-equiv.	6.6E-03	1.8E-02	7.8E-03
Agricultural land use	m²*a	0.8	5.3	1.3
Agricultural water use	L	4.8	18.1	6.3

Table 4. National origin of water and land used for agricultural food production per person and year[5]

Country	Unit	Animal products	Plant products	Total	Unit	Animal products	Plant products	Total
Argentina	l	282	0	282	m²*a	216	0	216
Austria	l	0	9	9	m²*a	0	1	1
Brazil	l	44	0	44	m²*a	216	0	216
Colombia	l	0	20	20	m²*a	0	2	2
Croatia	l	0	344	344	m²*a	0	2	2
Czech Republic	l	2	7	10	m²*a	25	20	45
Germany	l	2556	712	3268	m²*a	1353	317	1669
Denmark	l	6	9	15	m²*a	3	2	5
Ecuador	l	0	503	503	m²*a	0	3	3
Egypt	l	0	63	63	m²*a	0	0	0
Spain	l	0	2521	2521	m²*a	0	8	8
France	l	381	16	397	m²*a	15	12	27
Hungary	l	1	0	1	m²*a	4	0	4
Israel	l	0	160	160	m²*a	0	0	0
India	l	0	300	300	m²*a	0	2	2
Italy	l	0	647	647	m²*a	0	6	6
Maroc	l	0	15	15	m²*a	0	0	0
Netherlands	l	52	23	75	m²*a	9	22	31
Pakistan	l	0	2437	2437	m²*a	0	3	3
Poland	l	8	3	10	m²*a	17	13	30
Swaziland	l	0	12	12	m²*a	0	0	0
Thailand	l	0	884	884	m²*a	0	5	5
Turkey	l	0	126	126	m²*a	0	0	0
United Kingdom	l	1	712	713	m²*a	2	2	4
United States	l	0	925	925	m²*a	0	3	3
Viet Nam	l	0	293	293	m²*a	0	4	4
TOTAL	l	3333	10740	14073	m²*a	1861	425	2286

[5] Interpreting the results it has to be considered that results for animal based products depend on the assumption that production of fodder components is done like in Germany with the same import countries and import shares for each fodder component. Thus, shares of Germany are somewhat overestimated with respect to water and land use (see sections 2 and 4).

4. Discussion

Results show a high relevance of food consumption and food losses regarding environmental impacts: e.g. food consumption and food losses cause about 23 percent of the German greenhouse gas emissions per person[6] and the water used for German food production is about one third of the German households' water use (Destatis 2013).

In general, results show a similar dimension as results from previous studies which have been carried out to estimate environmental impacts of German food consumption. However, there are also differences. One reason for that is, that in this study both the whole life cycle from agriculture to consumption (including energy consumption for shopping trip, food storage and cooking) and also food losses at all life cycle stages have been considered which was not the case in previous studies

Wiegmann et al. (2005) calculated greenhouse gas emissions which are one quarter lower. They used a similar methodology but a different database. The results of Meier (2014) for greenhouse gas emissions are 9 percent lower. Meier also used a different database.

There are two main reasons for the differences: one is that Wiegmann et al. (2005) didn't calculate all food losses along the value chain, because data haven't been available in sufficient detail at that time. Meier (2014) didn't calculate energy consumption at household level for the shopping trip, cooling and cooking. The other reason is that both studies used the GEMIS database for basis data as electricity grid, fertilizer and chemicals production, transport. In contrast, in this study the ecoinvent database was used for basis data, GEMIS data were only used for material flows. Compared to the ecoinvent database greenhouse gas emissions in the GEMIS database are lower in most cases.

Regarding water consumption Meier (2014) calculated much higher water consumption. According to his results German food consumption is responsible for 32.5 m³ of water use per person and year which is more than twice as much as the results of this study. The main reason for that is that in Meier's study (Meier 2014) nuts count for about one third of water consumption of German food consumption. In this study nuts haven't been an own category, they have been subsumed in the category 'other fruits' and thus specific water use of nuts has not been taken into account. This and also other differences regarding the composition of the calculated food baskets explain differences in agricultural water use.

In contrast, with respect to land use results of Meier (2014), Wiegmann et al. (2005) and Kastner et al. (2012) are about 10% lower. There are two main reasons for this difference. One is that different data regarding land use have been used in the studies; the other that food losses have not been taken into account in all studies. Yield data in this study have been taken from GEMIS 4.81[7], which uses yield data from the Common Agricultural Policy Regionalized Impact Analysis (CAPRI) modelling system[8] in most datasets. GEMIS groups countries to Central, North, West and South Europe, and Germany has been assigned to Central Europe. Probably this leads to lower yields than typical for Germany.

Furthermore results of this study have to be discussed against the allocation methods used. For this purpose a sensitivity analysis has been carried out to analyze the influence of the allocation method used for milk cow keeping and processing of dairy products. In the sensitivity analysis both allocations have been changed to 100% allocation. Sensitivity analysis results show that this allocation influences results. With respect to all analyzed impact categories and inventory parameters results are 3 to 19% higher with 100% allocation. In particular regarding greenhouse gas emissions (8%), particulate matter formation (95%), terrestrial acidification (19%) and agricultural land use (18%) an effect of the chosen allocation can be shown (Figure 4).

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[6] http://www.umweltbundesamt.de/themen/klima-energie/klimaschutz-energiepolitik-in-deutschland/treibhausgas-emissionen/europaeischer-vergleich-der-treibhausgas-emissionen; Status: 8 May 2014
[7] http://www.gemis.de
[8] http://www.capri-model.org/

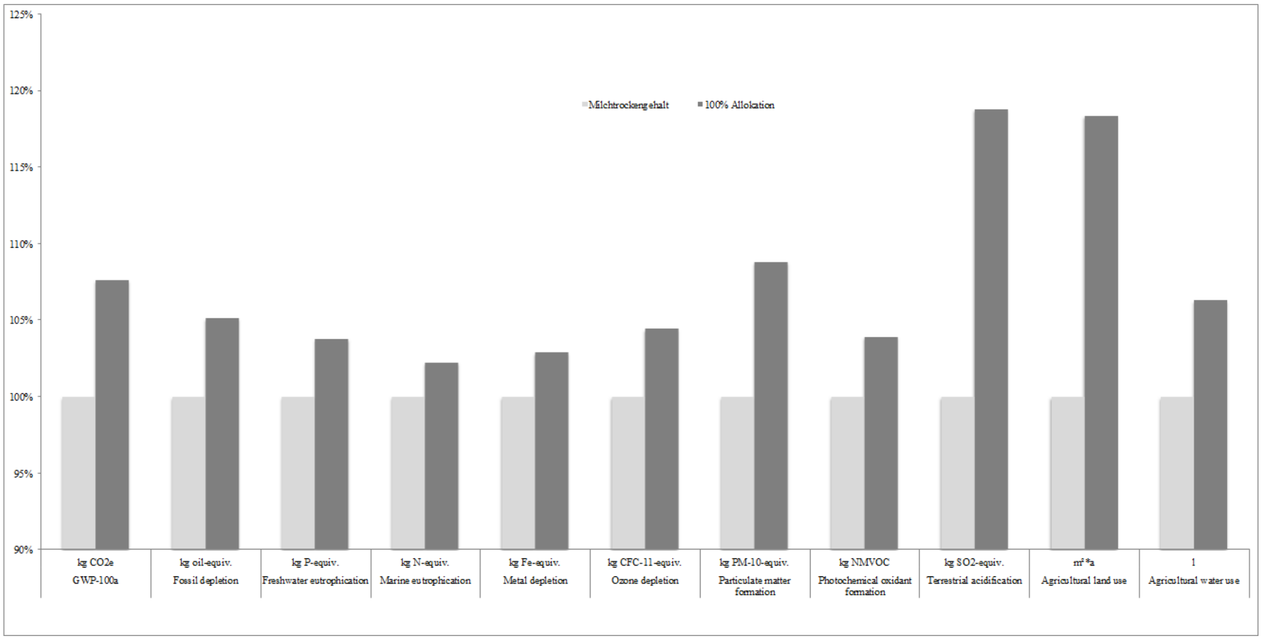

Figure 4. Differences in results with respect to allocation methods

Moreover, results have to be discussed against the assumptions and simplifications made. Thus, with respect to the chosen methodology it has to be considered that results for animal based products depend on the assumption that production of fodder components is done like in Germany with the same import countries and import shares for each fodder component. Thus, shares of Germany are somewhat overestimated with respect to water and land use.

Regarding the provenience of water consumption it has to be taken into account that in the case of rice no statistical data for the origin of consumed rice could be found. German trade statistics show only the import countries of processed rice (e.g. peeled rice). Thus, it was assumed that the world's largest rice exporters export rice to Germany at the same proportion as their share in the global rice market. Therefore, more precise trade statistics could change the results in the case of Pakistan.

5. Conclusion

The study shows the high relevance of food production regarding environmental impacts. In particular animal products are responsible for high environmental burdens in the German food basket. Losses (animal and plant based) along the product chains have a share between 13 and 20 percent in environmental impacts. With respect to reduce environmentally relevant food losses, measures should focus in particular to reduce food waste of animal origin like dairy products and meat. The most relevant points for reduction measures are agricultural production and consumption in households and out-of-home. In particular out-of-home consumption has a high share of spoiled food in relation to the total food used. Out-of-home consumption therefore also provides a good starting point for measures.

Nevertheless, better statistical and also environmental data are still needed to improve such kind of studies.

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Questions and comments can be addressed to: staff@lcacenter.org

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