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LCA FOR FOOD PRODUCTS

Gender as a factor in an environmental assessment of the consumption of animal and plant-based foods in Germany

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Abstract

Purpose Due to their production intensity, different foods of animal or plant origin play a crucial role in the assessment of the environmental impacts of human nutrition and diets. Based on a representative nutrition survey in Germany from the year 2006, a life cycle assessment (LCA) was conducted to quantify nutrition-related emissions of animal and plant-based foods (excluding beverages), with a special focus on the socio-demographic factor gender.

Materials and methods For the study, representative data sets concerning German food production and consumption were used. These were complemented by the Danish LCA Food database and other LCA data to analyse the impact of food imports. As regards environmental impact assessment, global warming potential (GWP) was assessed, which included emissions from direct land use change and land use (dLUC, LU), along with three inventory indicators (ammonia emissions, land use, blue water use). The following food groups were analysed from cradle-to-store and their impacts were evaluated and compared with each other: animal-based foods (meat products, milk products, egg products and fish products), plant-based foods (grain products, vegetables, fruits, potato products, margarine/oils, sugar/sweets). The reference year in the study is the year 2006.

Results and discussion For all indicators, the results show strong variation between the genders. Even if the physiologically different consumption patterns among men and women are adjusted on a weight basis, men show a higher impact in terms of GWP (CO_2 eq. +25%), ammonia emissions (+30%) and land use (+24%). In contrast, women demonstrate a higher water demand (+11%). These differences are primarily caused by a higher share of meat and meat products in the usual diet of men (+28%) as well as of fruit and vegetables in the diet of women (+40%). If men were to shift qualitatively to the usual diet of women, then 14.8 Mt CO_2 eq. and 60.1 kt ammonia emissions could be saved annually. Within the system boundaries of our study, this would translate into a reduction of 12% of CO_2 eq. and 14% of ammonia emissions. With regard to land use, this equals an area of 15,613 km^2 $year^{-1}$ (−11%), whereas the total blue water demand would be increased by 94 Mm^3 $year^{-1}$ (+7%). Limitations within this study are caused by the system boundaries cradle-to-store and are also due to the restricted set of environmental indicators which were analysed. Nonetheless, our results for GWP and land use are in keeping with previous studies. The results concerning ammonia and blue water use are limited when compared with other study results.

Conclusions The study shows that within one society distinct diet profiles with markedly different environmental impacts are already established. Taking cultural and physiological considerations among the genders into account, these differences could be seen as offering potential opportunities to strengthen sustainable diet profiles. Further research should also consider health impact assessments to ensure that

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alterations in diet profiles due to environmental constraints do not lead to disadvantageous public health effects. Particular attention should be paid here to potentially undernourished subgroups (such as the elderly, sick people, pregnant women).

Keywords Agri-food sector · Diet profiles · Diet shift · Direct land use change/land use (dLUC/LU) · Hybrid-LCA · Input–output analysis · National Nutrition Survey II · Nutrition patterns

1 Introduction

Human nutrition has a strong effect on environmental impacts. Taking political considerations into account (EC 2011), nutritionally acceptable und environmentally sound measures have to be developed to cope with current agro-ecological challenges: climate change, deforestation, biodiversity loss, water scarcity, pollution, etc. Various studies with a life cycle perspective have identified food supply as one of the main contributors to environmental impacts (Kramer et al. 1994; Quack and Rüdenauer 2004; Nijdam et al. 2005; Tukker et al. 2006). To facilitate political and economic decisions various life cycle assessments (LCA) have been elaborated: (1) either on a product level basis to localize hot spots in the life cycle of a single product (farming, processing, packaging, transportation, cooking and storing in the household/in restaurants, and waste management) or (2) on a diet basis to identify the most polluting food items or to compare dietary choices (Carlsson-Kanyama 1998; Jungbluth 2000; Taylor 2000; Davis et al. 2010; Muñoz et al. 2010; Tukker et al. 2011). Besides technical solutions (efficiency gains in production and processing) and a reduction of food losses, changes in diets respectively nutrition patterns are discussed to decrease environmental impacts of the agri-food sector (Stehfest et al. 2009; Popp et al. 2010). Here, we consider the influence of different mainstream dietary patterns. The primary objective of the research project was to quantify diet-related environmental impacts based on gender. Taking differences in the usual diet of men and women into consideration most polluting food items and processes get a closer look. Furthermore, we estimate the potential effects caused if men were to adapt to the diet profile of women.

2 Materials and methods

Besides agro-environmental data sets, population-specific nutrition data was used for the assessment. According to ISO 14040/14044 (2006) the four distinct steps of an LCA have been completed: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation. The reference year of the study is the year 2006.

2.1 System boundaries

The system boundaries include the following steps in the process chain: (1) agricultural production (including upstream processes), (2) processing, (3) transport/trade, and (4) packaging. The upstream processes of agricultural production include emissions from direct land use change and land use (dLUC/LU), emissions from fertilizer/pesticide production and emissions from the construction and use of buildings and machinery. Therefore the system boundaries are set cradle-to-store. Related emissions during food buying, in the use phase (cooking and storing in the household/in restaurants, etc.) or in the waste phase have not been taken into consideration in the study.

2.2 Nutrition data

Representative environmental assessments of food consumption patterns and diets can build upon several data sources: (1) food balance sheets (FBS, average consumption statistics on a yearly and country-specific basis, data provided by the FAO; www.faostat.org); (2) household budget surveys (HBS; detailed socio-economic and demographic consumption data concerning purchases on a household level, including food, beverages; country-specific, but not on a yearly basis; EC 2003); and (3) national nutrition surveys (NNS; detailed intake data on an individual level, country or region-specific, but not on a yearly basis; EFSA 2011). To distinguish between the different data sources the terms have to be clearly defined. 'Consumption' data deals with the question 'How much food was available?' and, therefore, in addition to the amounts eaten it also includes food wastage and food losses. This data is thus appropriate to serve as a basis for environmental assessment. Food 'intake' data is otherwise more applicable for answering the question of how much food was actually eaten. By converting the amounts eaten into nutrients, health impacts could be considered. Previous studies in Germany with a similar scope (Taylor 2000; Hoffmann 2002; Wiegmann et al. 2005; Woitowitz 2007) used nutrition-related intake data either from the German National Nutrition Survey I (Kübler et al. 1995), from household budget surveys (Federal Statistical Office, several volumes) or from their own surveys. In comparison to the German National Nutrition Survey I, which was compiled from 1985 to 1988 in the former West Germany (Kübler et al. 1995), this study was able to build partly upon the results of the German National Nutrition Study II (MRI 2008). The food intake data for this survey was collected in the years 2005 and 2006 among 13,000 inhabitants between the ages of 14 and 80 years across the whole country.

In this way, the German National Nutrition Survey II (NNS II) is representative for 68 million people — or 83% — of the total population. Representative subgroups are specified in the NNS II according to: gender, age groups, social groups and regions. In our study, we present the results concerning the socio-demographic factor gender. With regard to accuracy and representativeness, the survey establishes a solid stock for further statistical research that can be used via scientific use files.

2.3 Imports and exports of food

Due to the manifold trade relations of the German agri-food sector, it was impossible to include all imports and exports and their related environmental impacts in the assessment. Nevertheless, to approach this issue in a practical manner we consider only trade relations where Germany is a significant net importer. Hence the degree of self-sufficiency is far below 100%. Table 1 gives an overview of the degree of self-sufficiency for important commodities and food in the year 2006 (BMELV 2009). All imports of food and feed that are highlighted in grey are considered in the assessment.

Although self-sufficiency for butter and egg products is also below 100%, we do not consider related net imports. We assume for the exporting countries (for butter, mainly Ireland and the Netherlands; for eggs, mainly the Netherlands) the same production conditions as in Germany. Due to a lack of statistical information for fish we use the Danish LCA Food database (Nielsen et al. 2003), hence the question of self-sufficiency is trivial. The low self-sufficiency for oil cakes (mainly from soy and palm fruit) is considered indirectly in the feed compositions and thus influences the livestock products.

2.4 Environmental data of the agri-food sector

2.4.1 Production

Data provided by the project Greenhouse Gas Emissions from the European Livestock Sector (GGELS; Leip et al. 2010) was used for the production-related greenhouse gas (GHG) emissions of meat, milk and egg products. Within the GGELS project, several emissions of animal-based products were calculated at NUTS-2 level for the member states of the EU-27. The reference year in the GGELS project was the year 2004. With the modelling system CAPRI (Common Agricultural Policy Regionalised Impact Modelling System) the emissions of GHG, ammonia and nitrogen oxides were analysed. Besides conventional emissions from agricultural production and intermediate processing, emissions from direct land use change and land use (dLUC/LU), which occurred in European and non-European countries, were calculated by a Tier-1 approach in three different scenarios. Scenario 1 implements

Table 1 Degree of self-sufficiency of German food consumption in the year 2006

Foods	in %
Fresh milk, drinks	*119*
Cheese	*117*
Butter	*81*
Meat and processed meat	*101*
Egg products	*71*
Fish products	*25*
Grains	*109*
Vegetables	*36*
Fruits	*17*
Potatoes	*111*
Vegetal oils	*30*
Sugar	*136*
Feeds	
Wheat	*84*
Rye	*95*
Barley	*89*
Maize	*99*
Oil cakes	*33*

LUC/LU-related emissions from the conversion of areas with lower C-contents (grassland and savannahs), whereas scenario 3 can be considered as a maximum emissions scenario where the share of converted forests to arable land is higher. Scenario 2 applies a more likely mix of transition probabilities. Taking uncertainty and allocation issues into consideration, the results of scenario 2 were chosen for the impact assessment in this study (see Sensitivity analysis). Top–down data provided by the System of Environmental and Economic Accounting (SEEA; Schmidt and Osterburg 2011) was used for the production-related emissions of the plant-based foods in the year 2003. Due to underestimations of ammonia emissions for livestock products in Leip et al. (2010) we used the ammonia emissions based on Schmidt and Osterburg (2011), which fit better into the official data of ammonia monitoring in Germany. The extrapolation of the ammonia emissions we calculated according to product group results in 521 kt year^{-1}. This value is comparable to the statistical data of 597 kt ammonia emissions in the German agricultural sector in 2003 (Federal Statistical Office 2010). The difference could be explained by the fact that the official data refers to production, whereas our data refers to consumption. Thus all exports are included in the official data. Besides this, our data is lower since beverages are not included in our extrapolation. For data collection for fish, the Danish LCA Food database (Nielsen et al. 2003) was used. The production-related data concerning land and water usage was also provided by Schmidt and Osterburg (2011).

2.4.2 Processing, transport, packaging

For the process element ‘processing’, product-specific official agro-statistical data for the year 2006 was used (BMELV 2009). With regard to transportation in the German agri-food sector, official average transport distances were applied (Ministry of Transport 2010). Corresponding emissions and emissions from imported products were estimated based on average transport distances using the software GEMIS 4.6 (Institute of Applied Ecology 2010). GEMIS was also used to calculate the emissions from packaging/outer packaging on the basis of 11 different packaging materials (HDPE, LDPE, PS, PET, PP, glass, aluminium, steel, new/recycled cardboard, new/recycled paper, wood) for the year 2005. Product group-specific data concerning cooling and deep-freezing was provided by official statistics (BMELV 2009).

2.5 Analysed food groups, functional unit and agri-environmental indicators

According to the product group classifications in the German NNS II (MRI 2008), the following food groups were examined (Table 2). Since the underlying nutrition data of the NNS II had not yet been evaluated down to the level of all food ingredients when this LCA was conducted, assumptions had to be made concerning the food group ‘meals based on…’. To circumvent the uncertainties which are associated with this group of mixed ingredients, 67% (two thirds) were allocated on a mass basis to the respective main group due to the fact that the main part of the group ‘meal based on …’ contains the related ingredient. For example: 67% of the food group ‘meals based on eggs’ was allocated to ‘egg products’.

Table 2 Analysed food groups

Food group	Examples
Fresh milk, drinks	Whole milk, skim milk, milkshake, etc.
Creamy milk products	Yoghurt, cream, concentrated milk, etc.
Cheese, curd	Semi-/hard, soft cheese, pasta filata, curd, etc.
Butter	Whole fat butter (fat content >82%)
Meat products	Beef/veal, goat/lamb, pork or poultry
Processed meat	Sausages, salami, ham depending on animal species, etc.
Egg products	Fried eggs, egg salad, etc.
Fish products	Pure fish, fish salad, fish sticks, etc.
Grain products	Different breads, cakes, pasta, muesli, etc.
Vegetables	Salad, cooked vegetables/mushrooms/legumes, etc.
Fruits	Stone fruits, citrus fruits, fruit salad, etc.
Potato products	Potatoes, mash potatoes, potato salad, etc.
Margarine, oils	Oleomargarine, rapeseed oil, etc.
Sugar, sweets	Confectionery, table sugar, marmalade, chocolate, etc.

The basis for the environmental assessment was formed by the amounts of consumed products (as reported in the official food balance sheets). Since the German NNS II (MRI 2008) documents the *intake* of food products, a conversion of the observed amounts eaten (intake) to statistically available amounts (consumption) was implemented in the LCI. Unlike in former studies, which have estimated these conversion factors (CF), we used official consumption data from the year 2006 (BMELV 2009) and the corresponding data from the NNS II. Following this approach, the conversion could be embedded consistently in official statistical data. Since data concerning food waste was not collected as part of the German NNS II, we were unable to estimate where exactly in the food chain food wastage occurs. Table 3 gives an overview of the underlying intake amounts and the CF as well as the corresponding CO_2 eq., ammonia, land use and water use factors.

The functional unit is defined as 1 kg of *consumed* product.

Life cycle inventory and life cycle impact assessment One impact category was analysed in the impact assessment:

– Impact category:

  (i) Global warming potential (GWP) in kg CO_2 equivalents person^{-1} year^{-1} according to IPCC (2006)

Table 3 Gender-specific intake amounts, conversion factors and CO_2 eq., ammonia, land use and water use factors based on the functional unit

	Intake		CF intake/consumption	CO_2 eq.	NH_3	Land use	Water use (blue)	Modelled as
	Men kg person^{-1}	women year^{-1}		kg/kg	g/kg	m²/kg	l/kg	
Fresh milk, drinks	49.2	37.1	0.65	1.57	6.0	1.5	12.1	2004 data concerning GHG of German raw milk from Leip et al. (2010), conversion to milk products based on official fat and protein contents (BLE 2010) and EPD (2010). Data concerning NH_3, land and water usage in 2003 from Schmidt and Osterburg (2011). Data for processing based on 2006 official energy consumption in the German dairy sector from BMELV (2009). Transport, trade and packaging are estimated using average data for dairy products with GEMIS (Institute of Applied Ecology 2010).
Creamy milk products	28.8	33.5	0.75	2.93	12.9	3.3	18.,2	
Cheese, curd	17.1	16.3	0.76	7.83	41.5	10.6	45.7	
Butter	5.8	3.7	0.72	15.11	86.7	22.1	88.8	
Pork	34.1	17.7	0.45	8.86	32.7	8.6	28.5	2004 data concerning GHG of German meat production according to species from Leip et al. (2010). Data concerning NH_3, land and water usage in 2003 from Schmidt and Osterburg (2011). Data for processing based on 2006 official energy consumption in the German meat industry from BMELV (2009). Transport, trade and packaging are estimated using average data for meat products with GEMIS (Institute of Applied Ecology 2010).
Beef, veal	7.1	3.7	0.45	20.01	74.9	25.0	83.4	
Poultry	8.7	4.5	0.45	5.52	23.6	6.2	14.8	
Goat, lamb	1.6	0.8	0.45	14.42	71.9	6.4	86.0	
Egg products	7.1	5.6	0.49	2.87	19.6	4.0	8.4	2004 data concerning GHG for German egg production from Leip et al. (2010). Data concerning NH_3, land and water usage in 2003 from Schmidt and Osterburg (2011). Transport, trade and packaging are estimated using average data for egg products with GEMIS (Institute of Applied Ecology 2010).
Fish products	8.9	7.2	0.52	3.43	0.1	1.3	14.7	Data for cod, herring, shrimp and trout from the LCA Food database (Nielsen et al. 2003). Data for aquacultural production and feed composition from Pelletier et al. (2009). Data for processing based on 2006 official energy consumption in the German fish industry from BMELV (2009). Transport, trade and packaging are estimated using average data for fish products with GEMIS (Institute of Applied Ecology 2010).
Grain products	107.6	82.6	0.91	1.40	1.9	1.8	5.3	2003 data for German grain production from Schmidt and Osterburg (2011). Data for processing based on 2006 official energy consumption in the German milling, bakery and pasta sectors from BMELV (2009). Transport, trade and packaging are estimated using average data for grain products with GEMIS (Institute of Applied Ecology 2010).
Vegetables	67.3	74.1	0.81	0.75	0.7	0.5	27.4	2003 data for German vegetable production from Schmidt and Osterburg (2011). Data for imported vegetables from 2006 according to origin (Netherlands 45%, Spain 35%, Italy 14%, others 7%) from BMELV (2009). Water usage of imported vegetables from Mekonnen, Hoekstra (2010). Data for processing based on 2006 official energy consumption in the German vegetable/fruit sector from BMELV (2009). Transport, trade based on origin and packaging are estimated using average data for vegetables with GEMIS (Institute of Applied Ecology 2010).
Fruits	84.0	101.5	0.73	0.52	0.6	1.0	87.6	2003 data for German fruit production from Schmidt and Osterburg (2011). Data for imported fruits from 2006 according to origin (Spain 36%, Italy 21%, Ecuador 12%, Columbia 10%, Costa Rica 9%, others 12%) from BMELV (2009). Water use of imported fruit from Mekonnen, Hoekstra (2010). For GHG, NH_3 and land use of the production of imported fruit we used German data (Schmidt and Osterburg 2011). Data for processing based on 2006 official energy consumption in the German vegetable/fruit sector from BMELV (2009). Transport, trade based on origin and packaging are estimated using average data for fruit with GEMIS (Institute of Applied Ecology 2010).
Potato products	33.3	25.9	0.46	0.52	0.3	0.3	5.7	2003 data for German potato production from Schmidt and Osterburg (2011). Data for processing based on 2006 official energy consumption in the German potato industry from BMELV (2009).

Table 3 (continued)

	Intake		CF intake/consumption	CO_2 eq.	NH_3	Land use	Water use (blue)	Modelled as
	Men	women						
	kg person^{-1} year^{-1}			kg/kg	g/kg	m^2/kg	l/kg	
								Transport, trade and packaging are estimated using average data for potato products with GEMIS (Institute of Applied Ecology 2010).
Vegetal oils, margarine	4.7	3.7	0.74	2.07	5.3	3.4	14.8	2003 data for German oil seed production from Schmidt and Osterburg (2011). Imported vegetal oil was assumed as 100% olive oil, data from Molero (2006). Data for processing based on 2006 official energy consumption in the German oil/margarine industry from BMELV (2009). Transport, trade and packaging are estimated using average data for vegetal oils and margarine with GEMIS (Institute of Applied Ecology 2010).
Sugar, sweets	20.1	17.5	0.70	2.34	1.5	1.2	9.5	2003 data for German sugar production from Schmidt and Osterburg (2011). Data for cocoa production from Ntiamoah and Afrane (2008). Data for processing based on 2006 official energy consumption in the German sugar and sweets industry from BMELV (2009). Transport, trade and packaging are estimated using average data for sugar/sweets with GEMIS (Institute of Applied Ecology 2010).

CF conversion factor, *CO_2 eq.* CO_2 equivalents according to IPCC (2006), *NH_3* ammonia, *GHG* greenhouse gases

In addition, three inventory indicators were also analysed:

– Inventory indicators:

(ii) Ammonia emissions in g NH_3 person^{-1} year^{-1}
(iii) Land use in m^2 person^{-1} year^{-1}
(iv) Water use in l person^{-1} year^{-1} as expressed as blue water use according to Mekonnen and Hoekstra (2010)

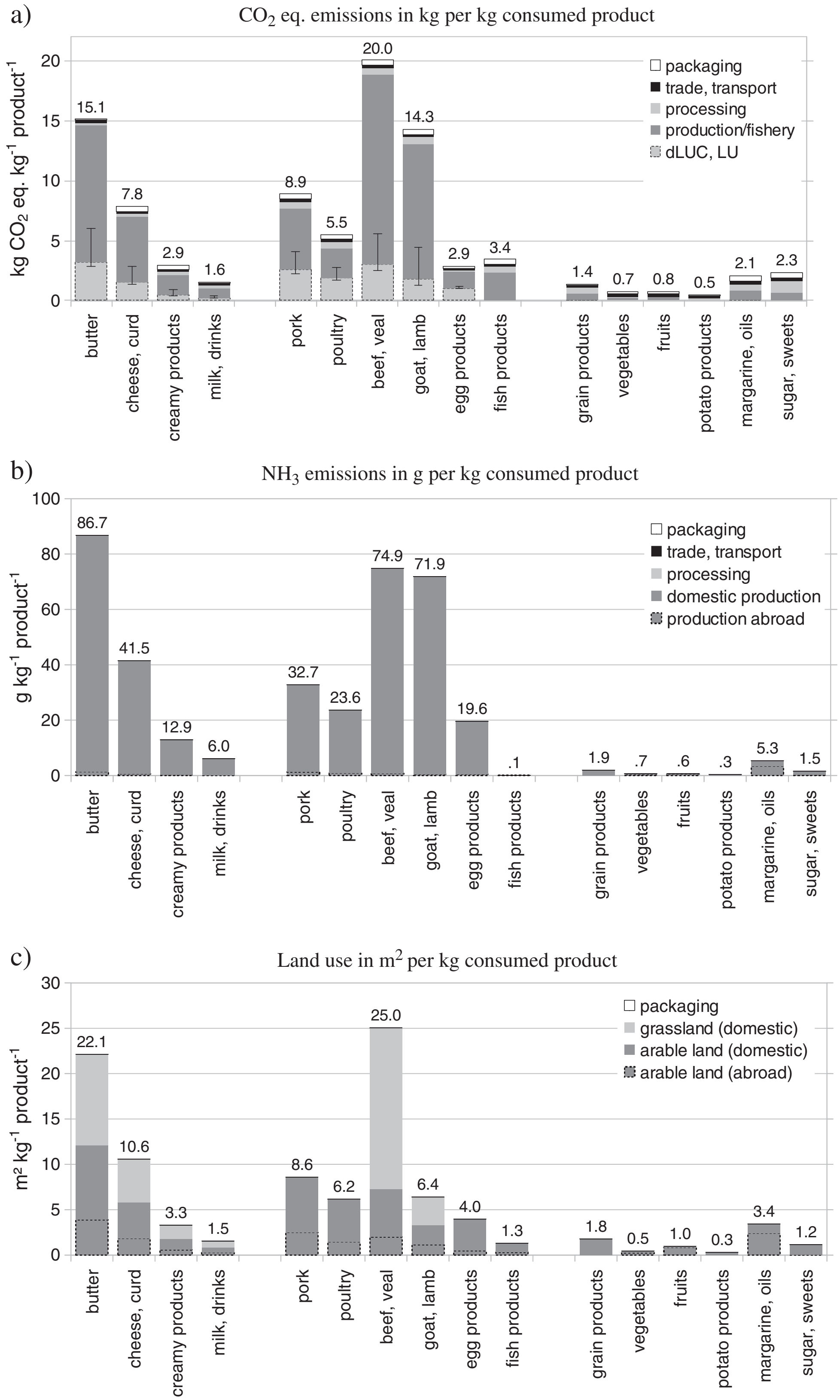
The reasons for choosing these environmental indicators were: (1) their high relevance in the environmental assessment of the agri-food sector and (2) the availability of up-to-date and consistent top–down data (at least for the German agri-food sector) that fit into the study design. Besides the global effects of GHG emissions on global warming in the assessment of agricultural and nutritional performance, a key parameter for eutrophication and acidification is ammonia (OECD 2001). The assessment of the eutrophication and acidification potentials was omitted from the analysis as no corresponding top–down data for the German agri-food sector was available.

In order to characterise land use further and to include the effect on different land types, we distinguish between arable land and grassland (pasture and meadow). Further, we incorporate forest area for the production of the packaging materials paper, cardboard and palettes. As regards water use, we consider 'blue water' only according to the methodology elaborated by Mekonnen and Hoekstra (2010). Whereas 'green water' refers to the rainwater consumed during crop production, 'blue water' covers ground and surface water that is needed for irrigation. 'Grey water' refers to the amount of water needed to dilute the pollutants in the effluents to an environmentally acceptable level (ibid.). In addition to production, we consider blue water use during food processing and for the packaging materials. Nevertheless, due to the ongoing scientific debate as to how to inventory and assess water use properly in LCAs, in this study we present inventory results only. In order to allow their proper interpretation, these have to be further characterised, normalized and weighted (depending on the LCIA method) according to source and regional scarcity implications. See Milà i Canals et al. (2009), Pfister et al. (2009) and Boulay et al. (2011) for further discussion.

To compare the impacts of the different animal- and plant-based foods and to evaluate the influence of the distinct life cycle stages in relation to each other, the food items were analysed based on the functional unit of 1 kg consumed product (Fig. 1).

GHG emissions Figure 1a shows the absolute composition of the CO_2 eq. emissions of the products analysed. In comparison to plant-based foods, animal-based foods have a substantially higher impact in the categories analysed,

Fig. 1 LCIA and LCI results per functional unit. **a** CO_2 eq. emissions in kg per kg consumed product; **b** NH_3 emissions in g per kg consumed product; **c** land use in m^2 per kg consumed product; **d** blue water use in l per kg consumed product



which is mainly caused by the sector 'agriculture/fishery' and associated emissions from dLUC/LU. With the exception of 'grain products' and 'margarine/oils', dLUC/LU-related emissions occur mainly for animal-based foods. Due to their very small contribution, dLUC/LU-related emissions were not analysed for the food groups 'vegetables', 'fruits' and 'sugar,

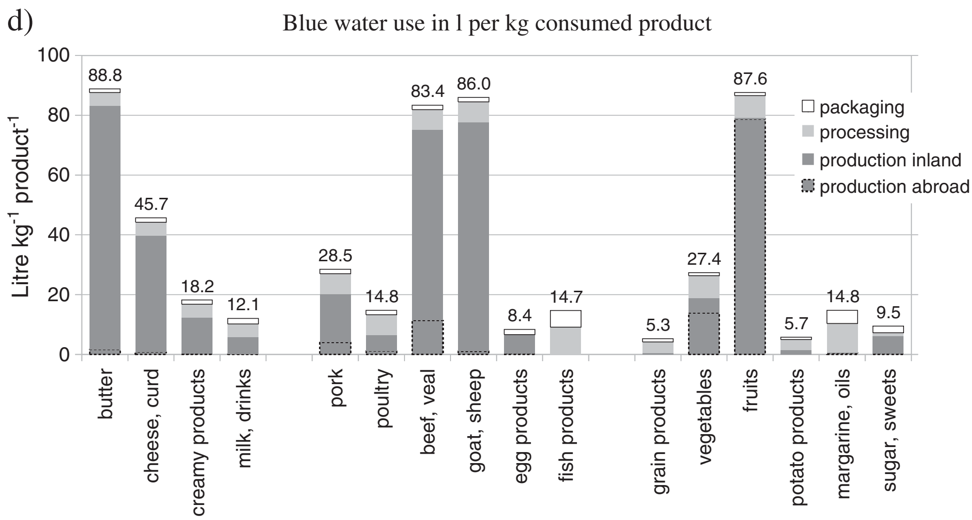


Fig. 1 continued.

sweets'. Although dLUC/LU-related impacts may be relevant for fish raised in aquaculture, we omit this due to a lack of resilient data. The whiskers in Fig. 1 refer to the emissions from dLUC/LU and correspond to the minimum (scenario 1) and maximum (scenario 3) in the report of Leip et al. (2010). A relative comparison of the different animal-based foods shows that dLUC/LU emissions could account for up to 40% of the total carbon footprint for poultry/eggs and pork, all monogastrics with a high share of protein and fat-rich components in the feed. Nevertheless, the highest carbon footprint occurs for ruminant meat, whereas the share of dLUC/LU emissions in the carbon footprint is smaller. The different carbon footprints for the milk products were allocated according to their statistically monitored fat (4.1%) and protein content (3.4%) in the year 2006 (BMELV 2009). This methodology did not include carbohydrates since carbohydrates are not monitored in the official milk statistics (BLE 2010). Data for the impact assessment of fish/fish products was provided by the LCA Food database (Nielsen et al. 2003). For calculating a typical 'average fish' consumed in Germany, consumption data for the year 2006 was used (BLE 2009). There, 95% of the fish consumption monitored is derived from 13 species. The species consumed the most were analysed and the corresponding impact was divided given its share in the consumption data. These are: pollack/cod (57%), herring (28%), shrimp (9%) and trout (6%). Of these four species, shrimp and trout are very likely produced in aquaculture and therefore nourished by additive agricultural feeds that subsequently cause emissions from dLUC/LU. Unfortunately, there was no related data available and thus no corresponding effect is given in Fig. 1a.

Ammonia emissions (Fig. 1b) Ammonia emissions are dominated by animal-based foods and occur mainly in the agricultural sector. They occur as a consequence of manure production and correlate with the manure amounts. Ammonia emissions from abroad as well as from processing, transport/trade and packaging are negligible.

Land use (Fig. 1c) The ruminant-derived products 'beef, veal', 'cheese, curd' and 'butter' show the highest land demand per functional unit. Nevertheless, due to a high share of roughages from domestic grasslands (up to 70%), their demand for foreign arable area is lower (below 18%). In contrast, the foreign demand for arable land is highest for pork and poultry (up to 29%) and for vegetables and fruits (up to 87%). Extrapolated on the basis of official consumption data, the total foreign area demand covers 42,000 km^2 year^{-1}, or 31% of the total agricultural area of Germany, with 11,157 km^2 for pork meat, 8,923 km^2 for milk products, 8,783 km^2 for fruit and 2,027 km^2 for poultry meat.

Water use (Fig. 1d) Although water origin differs greatly, we find the highest blue water demand for butter, fruit and ruminant meat. Due to the low self-sufficiency for fruits (see Table 1), 90% of the blue water use for fruits is virtually imported from the producer countries (see Table 2). Extrapolated on the basis of official consumption data, the total blue water demand covers 1,767 Mm^3 year^{-1}, with 959 Mm^3 year^{-1} (54%) being caused abroad, 415 Mm^3 year^{-1} (23%) needed in domestic production and 310 Mm^3 year^{-1} (18%) used during processing. Blue water needed for packaging accounts for 84 Mm^3 year^{-1}, or 5%.

3 Results

Based on the nutritional data concerning food intake (MRI 2008) and the CF calculated (see Table 2), related CO_2 eq. and ammonia emissions as well as land and water use differ quite heavily between the genders. As shown in Fig. 2a, men

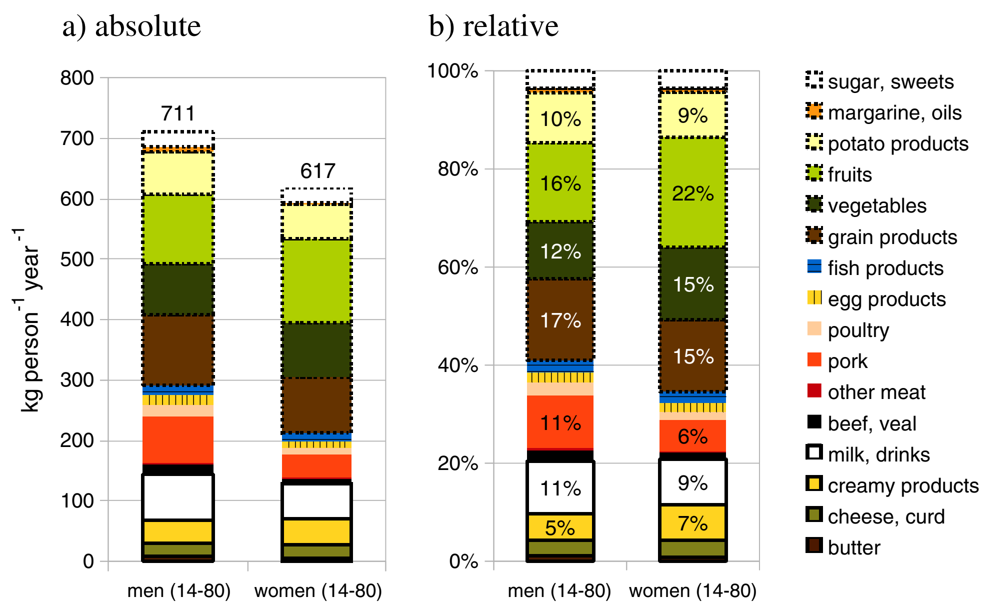


Fig. 2 Consumption profiles according to gender: **a** absolute, **b** relative

consumed 711 kg and women 617 kg of animal and plant-based foods in the year 2006. Thus men consumed 15% more food.

Related GHG emissions (Fig. 3a) of men (2,201 kg CO_2 eq. person^{-1} year^{-1}) exceed those of women (1,533 kg CO_2 eq. person^{-1} year^{-1}) by 44%. Both GHG profiles are dominated by meat and processed meat products: men's by 52%, women's by 39%. As Fig. 4a shows, major GHG emissions occur during the food production stage, with a significant impact of emissions from dLUC/LU (men: 18%, women: 16% of the total GWP). With regard to the depicted scenarios, the impact of dLUC/LU-related emissions could vary in the diet between 16 and 30% for men and 14 and 27% for women. This issue is part of the sensitivity analysis.

The consumption-related NH_3 profiles (see Fig. 3b) are both dominated by animal-based foods (men: 94%, women: 92%). Among all the impact indicators analysed we were able to observe the highest difference between the genders for ammonia: Men's emissions exceeded women's by 50%. Nearly all of the emissions occur during the food production stage (see Fig. 4b, men: 96%, women: 95%). The contributions of processing, transport, trade and packaging are negligible.

The data in Fig. 3c for land use is similarly as pronounced as that in Fig. 3a for the GWP. Men's consumption-related land use (2,361 m^2 person^{-1} year^{-1}) is 43% higher than women's (1,650 m^2 person^{-1} year^{-1}). Both land use profiles are dominated by meat and processed meat products: men's by 50%,

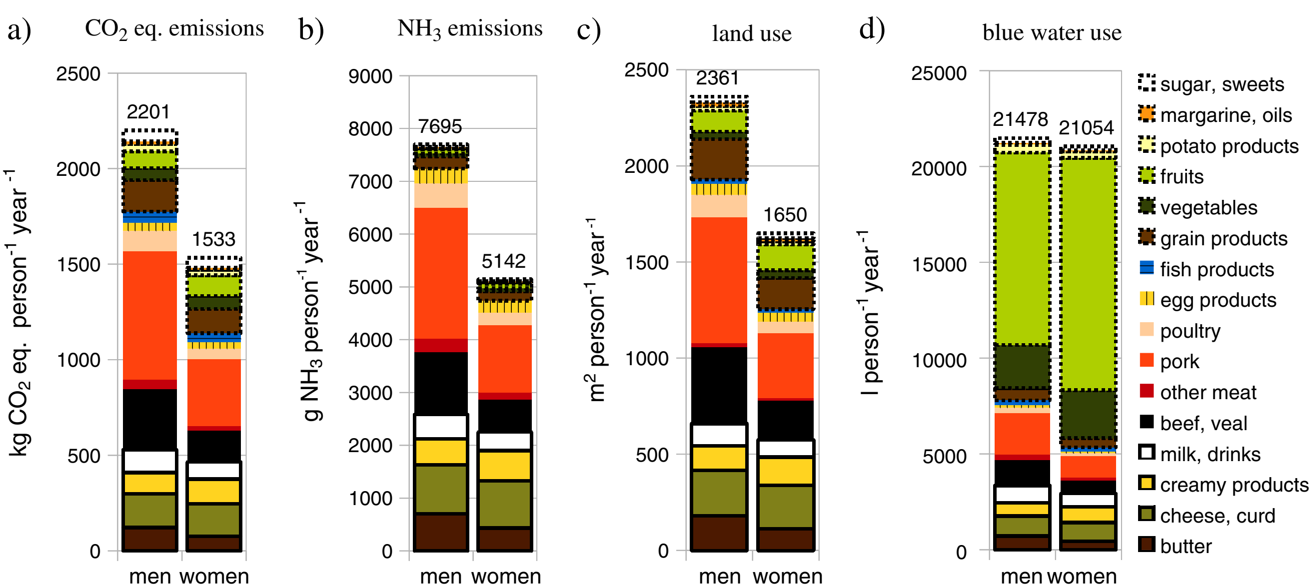


Fig. 3 Consumption-related CO_2 eq. and NH_3 emissions, land and water use based on food products. **a** CO_2 eq. emissions, **b** NH_3 emissions, **c** land use, **d** blue water use

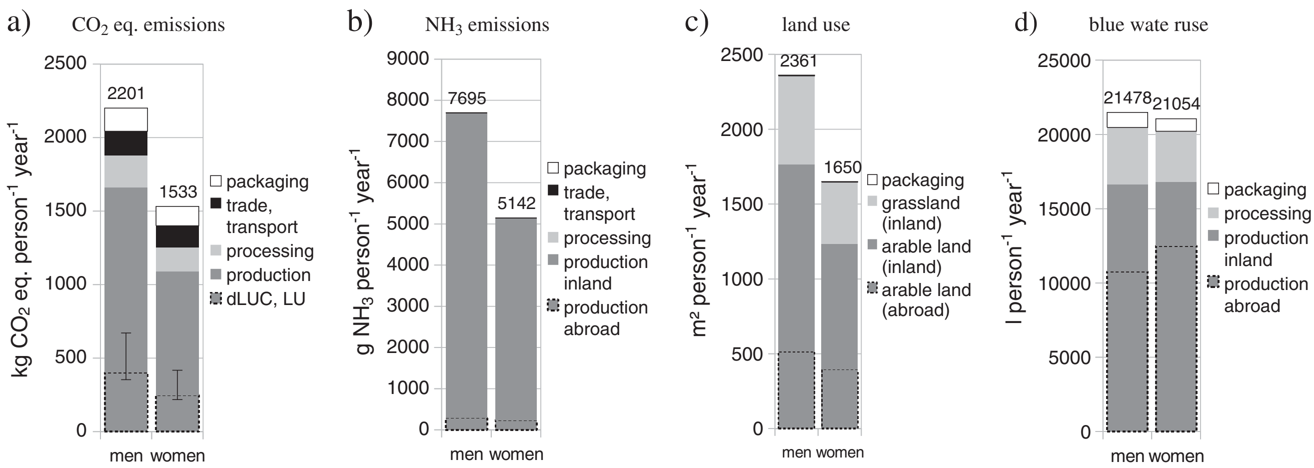


Fig. 4 Consumption-related CO_2 eq. and NH_3 emissions, land and water use based on life cycle stage and origin. **a** CO_2 eq. emissions, **b** NH_3 emissions, **c** land use, **d** blue water use

women's by 37%. In comparison to animal-based foods, the land use impact of plant-based foods in both diets is relatively low (for men: 18%, women: 24%). The distribution of land use according to land types and origin is almost equal among the genders (men: domestic arable land 53%, arable land abroad 22%, domestic pasture 25%, women: domestic arable land 51%, arable land abroad 24%, domestic pasture 25%). As mentioned in chapter 2, due to their high degree of self-sufficiency imports of ruminant-derived products are not considered in this study.

Our results concerning blue water use (see Fig. 3d) differ considerably. Women's consumption-related water use (21,054 l person^{-1} year^{-1}) is almost as high as men's (21,478 l person^{-1} year^{-1}). In contrast to the other impact indicators analysed, the water profile of both genders is dominated by plant-based foods (men: 64%, women: 75%). The high share of water use in production abroad is remarkable (men: 50%, women: 59%), and the same is the case during processing (men: 18%, women: 16%). Packaging accounts for 5% of water use (see Fig. 4d).

Compared with official consumption data for 2004–2006, the consumption of the products analysed has an overall impact of 15.9% of national GHG emissions, 84.1% of ammonia emissions, 47.1% of land area and 4.4% of national water withdrawal (our own calculations based on Federal Statistical Office 2010).

For the year 2004, the Federal Statistical Office (2010) documents a nationwide water withdrawal of 40,537 Mm^3, with 1,767 Mm^3 (4.4%) able to be allocated to the food products analysed.

3.1 Adjustment

To quantify the impacts that would be seen if men were to change their diet and adapt to the diet profile of women, the quantitatively different consumption profiles were adjusted to compare solely qualitative differences. Therefore, women's minor consumption was elevated by the observed 15%. Figure 5a shows that after the adjustment men's consumption profile is dominated by animal-based foods, mainly meat and processed meat products, butter and fresh milk products, as well as grain products. In contrast fruits, vegetables and creamy milk products are more pronounced in the consumption profile of women. The impact assessment with the adjusted diets reveals that men's impacts are higher: GHG +25% (+436 kg person^{-1} year^{-1}), ammonia +30% (+ 1,771 g person^{-1} year^{-1}), land use +24% (+460 m^2 person^{-1} year^{-1}) (see Fig. 5b, c, d).

In contrast, women's water use exceeds men's by 11% (+ 2,778 l person^{-1} year^{-1}) due to the higher share of water-intensive fruits and vegetables in the adjusted diet.

3.2 Extrapolation

In a further calculation step, the total changes to GHG and ammonia emissions as well as land use and water use alterations were analysed based on what would potentially happen if men were to shift qualitatively to the consumption profile of women. Taking into consideration the 33.9 million men (aged 14–80 years) who are represented by the NNS II (MRI 2008), 14.8 Mt CO_2 eq. emissions could be saved per year. Within the system boundaries cradle-to-store this would result in a 12% reduction of CO_2 eq. emissions (Table 4). Here, emissions in the production stage would be lowered by 14%, emissions from processing by 9% and from packaging by 2%. The major influence was observed for dLUC/LU-related emissions, with a decrease of 18%. In contrast, related emissions from transport and trade were increased by 2%.

With regard to ammonia, there would be a reduction of 60.1 kt year^{-1} (or 14% within the system boundaries). Nearly all of this decrease (99%) would occur in the domestic production stage.

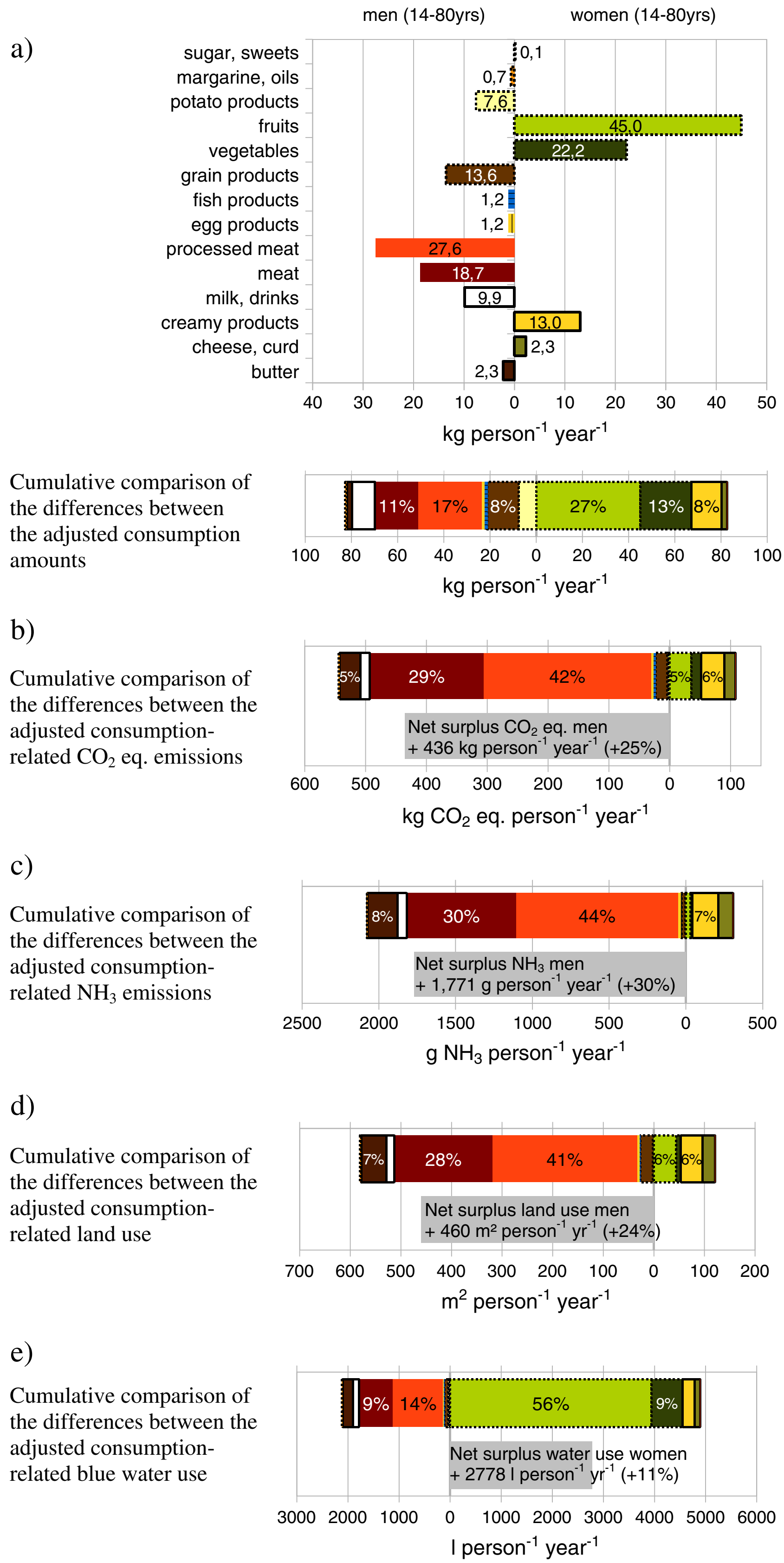


Fig. 5 Comparison of the adjusted consumption profiles according to: **a** consumption amounts, **b** CO_2 eq. emissions, **c** ammonia emissions, **d** land use and **e** water use

Table 4 Environmental alterations due to an adapted consumption profile of men

CO_2 eq. emissions	Consumption-related CO_2 eq. emissions		Consumption-related CO_2 eq. emissions, if men were to adapt to women's diet profile	
	kg person^{-1} year^{-1}	total in Mt year^{-1}	kg person^{-1} year^{-1}	total in Mt year^{-1}
Men (14–80 years)	2,201	74.7	1,766	59.9
Women (14–80 years)	1,533	52.8	1,533	52.8
Sum in Mt		127.6		112.8
CO_2 eq. savings in Mt (in %)				−14.8 (−12%)
NH_3 emissions	Consumption-related NH_3 emissions		Consumption-related NH_3 emissions, if men were to adapt to women's diet profile	
	g person^{-1} year^{-1}	total in kt year^{-1}	g person^{-1} year^{-1}	total in kt year^{-1}
Men (14–80 years)	7,695	261.2	5,925	201.1
Women (14–80 years)	5,142	177.3	5,142	177.3
sum in kt		438.5		378.4
NH_3 savings in kt (in %)				−60.1 (−14%)
Land use	Consumption-related land use		Consumption-related land use, if men were to adapt to women's diet profile	
	m² person^{-1} year^{-1}	total in km² year^{-1}	m² person^{-1} year^{-1}	total in km² year^{-1}
Men (14–80 years)	2,361	80,131	1,901	64,517
Women (14–80 years)	1,650	56,893	1,650	56,893
Sum in km²		137,024		121,411
Savings in km² (in %)				−15,613 (−11%)
Blue water use	Consumption-related water use		Consumption-related water use, if men were to adapt to women's diet profile	
	l person^{-1} year^{-1}	total in Mm^3 year^{-1}	l person^{-1} year^{-1}	total in mm^3 year^{-1}
Men (14–80 years)	21,478	728	24,256	823
Women (14–80 years)	21,054	725	21,054	725
Sum in m³		1,454		1,549
Additional demand in Mm^3 (in %)				94 *(+7%)*

In terms of land use, an area of 15,613 km^2 would be freed up, which means a reduction of 11% within the set system boundaries. The area freed would consist of 61% arable land (domestic), 25% grassland (domestic) and 13% arable land (abroad).

In contrast, we observed a higher net water demand of 7%, or 94 Mm^3, within the system boundaries. Although water use for domestic production would decrease by 9%, or 31 Mm^3 year^{-1}, water use abroad would be augmented by 16%, or 123 Mm^3 year^{-1}. Changes caused by processing and packaging would be negligible.

3.3 Sensitivity analysis

The uncertainty deriving from emissions of direct land use change/land use (dLUC/LU) was considered in the sensitivity analysis. The general aim of this part of the study was to quantify the impact of different dLUC/LU-related scenarios. In accordance with Leip et al. (2010), emissions from dLUC/LU were based on scenario 2. Apart from 'no effect' of dLUC/LU, scenarios 1 and 3 from Leip et al. (2010) were also included in the sensitivity analysis and compared with each other (Table 5). Here, scenario 1 implements dLUC/LU-related emissions from the conversion of areas with lower C contents (grassland and savannahs), whereas scenario 3 can be considered as a maximum emissions scenario where the ratio of converted forests to arable land is higher. Scenario 2 applies a more likely mix of transition probabilities.

The sensitivity analysis shows that dLUC/LU-related emissions demonstrate a stronger impact in the consumption-related CO_2 eq. emissions of men: These vary from −18% in the 'no dLUC/LU' scenario to +12% in dLUC/LU scenario 3 (see Table 5). The related impact for women is slightly lower,

Table 5 Sensitivity analysis based on emissions from dLUC/LU

CO_2 eq. emissions		Basis scenario (dLUC/LU scenario 2)	vs.	No dLUC/LU	dLUC/LU scenario 1	dLUC/LU scenario 3
Men (14–80 years)	kg person^{-1} year^{-1}	2,201		1,799	2,152	2,469
	in %			−18	−2	12
Women (14–80 years)	kg person^{-1} year^{-1}	1,533		1,285	1,503	1,702
	in %			−16	−2	11
Mean (14–80 years)	kg person^{-1} year^{-1}	1,864		1,540	1,825	2,083
	in %			−17	−2	12
Sum	Mt year^{-1}	127.6		105.3	124.9	142.5
				−17	−2	12
Share of dLUC/LU-related emissions	in %	17		0	16	26
Total CO_2 eq. savings, if men were to adapt to diet profile of women	Mt year^{-1}	14.8		10.8	14.3	17.3
	in %			−27	−3	17

varying from −16% in the 'no dLUC/LU' scenario to +11% in dLUC/LU scenario 3. This smaller variation derives mainly from the fact that women's consumption of dLUC/LU-intensive products is lower (mainly meat products). On average dLUC/LU-related emissions vary from −17% in the 'no dLUC/LU' scenario to +12% in scenario 3. Taking the total reference population into consideration (aged 14–80 years), consumption-related CO_2 eq. emissions of animal and plant-based foods vary from 105.3 Mt year^{-1} in the 'no dLUC/LU' scenario to 142.5 Mt year^{-1} in scenario 3 (difference: 37.1 Mt year^{-1}), with a share of dLUC/LU-related emissions of up to 26% in scenario 3. Possible total CO_2 eq. emission savings if men were to adapt to the dietary profile of women vary from 10.8 Mt year^{-1} in the 'no dLUC/LU' scenario to 17.3 Mt year^{-1} in scenario 3.

4 Discussion

Taking the different system boundaries into consideration, our results are comparable to those of other studies. Taylor (2000) analysed the carbon footprint of an average German citizen from cradle-to-fork (including household) by using an LCA approach. If emissions from dLUC/LU, which were not considered in the analysis by Taylor (2000), and from the household are neglected — to compare the results within the same scope — then Taylor (2000) calculated 1,440 kg CO_2 eq. person^{-1} year^{-1}. Although we did not cover beverages in our analysis, our average result of 1,540 kg CO_2 eq. person^{-1} year^{-1} (without dLUC/LU) is 7% higher. The differences could be explained by different approaches (LCA/input–output) and inventory data used. Taking the whole life cycle into account, Muñoz et al. (2010) calculated the carbon footprint of an average Spaniard to be 2.1 t CO_2 eq. person^{-1} year^{-1}. Combining input–output with LCA data, Jungbluth et al. (2011) calculated the carbon footprint of an average Swiss person to be 12 t CO_2 eq. person^{-1} year^{-1} — of this, 17%, or 2.0 t CO_2 eq. person^{-1} year^{-1}, are attributable to nutrition. GHG emissions were also examined by Carlsson-Kanyama (1998) for different diets, leading to GHG emissions in the range of 420–3,800 kg CO_2 eq. person^{-1} year^{-1}. Given the level of uncertainty in these kinds of studies, these values can be considered to fit rather well.

With regard to diet-related land requirements, other studies have had a focus either on national average values or on specific diets. Gerbens-Leenes and Nonhebel (2005) calculated similar figures for an average citizen in the Netherlands, with 1,909 m^2 person^{-1} year^{-1} in 1990, but did not distinguish between different land types and origin. Peters et al. (2007) analysed the land requirements for 42 different diets, whereby the area ranged from 1,800 to 8,600 m^2 person^{-1} year^{-1}, depending on the consumption of meat and eggs as well as calories from fat. The area demands we have calculated (men: 2,361 m^2 person^{-1} year^{-1}, women: 1,650 m^2 person^{-1} year^{-1}, mean: 2,003 m^2 person^{-1} year^{-1}) are comparable with these results.

It should be noted that, in terms of water, our results include 'blue water' only. Therefore they are not comparable to other studies (Sonnenberg et al. 2009; Leenes 2006; Hoekstra and Chapagain 2006) that consider both 'blue' and 'green' water. For agricultural products, Hoekstra and Chapagain (2006) calculated an average water footprint ('blue' and 'green') of 1,038 m^3 person^{-1} year^{-1}, but did not differentiate between 'blue' and 'green'. Taking the fact into account that blue water contributes just a minor part to total water demand, our average result of 21 m^3 person^{-1} year^{-1} is understandable. To strengthen the water impact assessment in the analysis of complete diets, discussed methodological problems (Boulay et al. 2011; Pfister et al. 2009; Milà i Canals et al. 2009) in the LCI and in the LCIA (characterisation, normalization, weighting) have to be solved and further developed.

Since the underlying nutrition data of the NNS II (MRI 2008) had not yet been evaluated down to the level of all food ingredients when this LCA was conducted, several assumptions had to be made. The food groups ‘soups’, ‘sauces’ and ‘snacks’ were not examined directly in the LCA, since a clear allocation based on the ingredients was not possible. Furthermore, the intake of meat products affected by various animal species had not been finally evaluated in the NNS II, and the official average consumption ratios for the year 2006 were used (BMELV 2009). As no gender-specific data concerning food consumption was available on a household level (buying, storing, preparing, wasting), we excluded this life cycle stage from our assessment and analysed the environmental impacts just from cradle-to-store. For fish products, we relied on the LCA food database (Nielsen et al. 2003), which has been built following a consequential approach to system boundaries, allocation and data selection, whereas our study followed an attributional approach. On the other hand, to include possible trade-offs and interlinkages in the adjustment scenario more realistically, a consequential approach would be necessary. Thus, our adjustment scenario could lead to biased results. Concerning milk and milk products, it is favourable to include carbohydrates in the allocation of the distinct milk products, to conduct the allocation on a dry mass basis (EPD 2010; Dairy et al. 2010). But from a statistical point of view, this is currently not viable in Germany since the sugar/carbohydrate content of milk delivered to dairies is not monitored regularly (BLE 2010). Therefore the allocation applied in this study was conducted according to the monitored fat and protein content of the several milk products. Due to the manifold trade relations in the agri-food sector, it was not possible to include all imports and exports and their related environmental impacts in the assessment. To include this issue in a practical manner, we consider only trade relations where Germany is a significant net importer, but have to point out that this could also be a reason for biased results.

5 Conclusions

In order to deal with agro-environmental challenges in the future, further development of viable nutrition strategies is crucial. The study shows that within one society distinct diet profiles with markedly different environmental impacts are already established. Taking cultural and physiological considerations among genders into account, these differences could be seen as offering potential opportunities to strengthen more sustainable nutrition patterns. Further research should bring nutrition-related reduction potentials together with health impact assessments to ensure that alterations in diet profiles due to environmental constraints do not generally cause disadvantageous public health effects. Special attention should be paid here to potentially undernourished subgroups (such as the elderly, sick people, pregnant women).

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