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Research report

Balancing virtual land imports by a shift in the diet. Using a land balance approach to assess the sustainability of food consumption. Germany as an example ☆

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ABSTRACT

Nutrition is considered as one of the main drivers of global environmental change. Dietary patterns in particular, embedded in the international trade of foods and other biomass based commodities, determine the dimension of beneficial or harmful environmental impacts of the agri-food sector – both domestically and abroad. In this study we analysed different dietary scenarios from a virtual land flow perspective, based on representative consumption data for Germany in the years 2006 and 1985–89. Further we identified the consumer groups that would have to adapt most to balance Germany's virtual land import and analysed the impact reduced food wastage. For the study, official data sets concerning production, trade and consumption were used. We derived land use data from environmentally extended input–output data sets and FAO statistics. The conversion of agricultural raw products to consumed commodities is based on official processing and composition data. Subgroup-specific intake data from the last representative National Nutrition Survey in Germany were used. We analysed 42 commodities, aggregated into 23 product groups, seven land use types and six nutrition scenarios. The results show that in the baseline scenario the average nutrition in the year 2006 leads to a virtual land import of 707 $m^2\ p^{-1}\ a^{-1}$, which represents 30% of the total nutrition-induced land demand of 2365 $m^2\ p^{-1}\ a^{-1}$. On the other hand, the German agri-food sector exports virtual land, in the form of commodities, equivalent to 262 $m^2\ p^{-1}\ a^{-1}$. In this paper we calculate that the resulting net import of virtual land could be balanced by way of a shift to an officially recommended diet and a reduction in the consumption of stimulants (cocoa, coffee, green/black tea, wine). A shift to an ovo-lacto-vegetarian or vegan diet would even lead to a positive virtual land balance (even with maintained consumption of stimulants). Moreover, we demonstrate that a shift in the average diet profile could lead to maintained or even expanded export competitiveness and simultaneously enable environmental benefits. Since such a diet shift complies with official dietary recommendations, it follows that public health benefits may well result. We show further that a reduction of avoidable food losses/wastage would not be sufficient to level out the virtual land balance of the average nutrition in Germany. Regarding the dietary developments in the last 20 years, we argue that a dietary shift resulting in a zero land balance is within reach. The population groups that would have to be addressed most are younger and middle-aged men. Nevertheless, women's land saving potentials should not be ignored neither. Due to the fact that a western-style diet prevails in Germany, we argue that our basic findings are applicable to other industrialised and densely populated countries.

Introduction

In the current debate concerning land competition and large scale foreign land acquisitions (informally known as land grabbing), international trade and thus trade in virtual land, in particular trade flows to industrialised countries, are discussed as

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influencing factors on environmental degradation and societal disturbance in developing nations (EC, 2013; Lenzen et al., 2012; Pearce, 2012; Smith, Gorddard, House, McIntyre, & Prober, 2012). In the EU several proposals have been put forward to include in the reform of the Common Agricultural Policy (CAP, 2014–2020) also measures to decrease Europe's import dependency from crops with a high land occupation abroad, mainly leguminous protein plants (ARC, 2012; EP, 2011; WWF, 2011). Positive effects of reducing the virtual land import encompass less environmental pressure on deteriorating ecosystems in main producer countries – e.g., Brazil, Argentina (EC, 2013; Fearnside, 2001; Lenzen et al., 2012; Morton et al., 2006) – as well as positive equity effects in these countries, if corresponding land and nutrition policies are managed properly (Lipton, 2009; Wahlqvist, McKay, Chang, & Chiu, 2012).

Furthermore, reducing virtual land import necessitates increasing domestic production of protein crops. In Germany the Federal Ministry of Food, Agriculture and Consumer Protection launched a corresponding 'Protein crops strategy' (BMELV, 2012). This aims at stimulating the domestic production of protein plants, namely soya, beans, peas, lentils, lupines, chick peas, alfalfa/lucerne and clover, and thus at diminishing virtual land imports. Besides a reduced import dependency doing so features further environmental as well as economic benefits. In environmental terms, potential benefits result from inclusion of leguminous protein plants in crop rotation (Crews & Peoples, 2004; Deike, Pallutt, Melander, Strassemeyer, & Christen, 2008; Köpke & Nemecek, 2010; Nemecek et al., 2008; Sinclair & Vadez, 2012). Economic benefits are linked to decreasing dependency on volatile world market prices (Richthofen et al., 2006; Schäfer & Lütke Entrup, 2009) as well as the creation of new income opportunities for European farmers through marketing of GMO-free products as part of a product quality scheme (JRC EC, 2012). However, contra these arguments industry and business associations have expressed concerns that promoting the domestic production of leguminous protein plants may push the production of established high-yield crops in Europe (mainly maize, grains and oilseed rape) aside, leading to less productivity and competitiveness on the world market due to an underutilized potential of relative cost advantages (OVID, 2012; UECBV, 2012).

Finally, in so far as domestic production of protein crops cannot completely substitute current imports, reducing virtual land imports involves replacing consumption of animal protein (e.g. meat, milk, eggs) with consumption of plant protein. This, in particular the reduction of red meat, comes along with positive health impacts, like a reduced chronic disease risk and a lower overall mortality (Aiking, Boer, & Vereijken, 2006; Belski et al., 2010; Darmadi-Blackberry et al., 2004; Fechner, Schweiggert, & Hasenkopf, 2011; Fleddermann et al., 2013; Messina, 2010; Weiße et al., 2010).

By applying a theoretical framework of sustainable development (SD) and inter-/intra-generational justice we reconsider the views mentioned from a broader perspective and present a possible solution, which combines their advantages while relativising corresponding criticism. SD globally functions as a leading role model for shaping (future) development. However, besides this general agreement it is not at all evident what claims for SD actually imply. In line with the Brundtland-definition we conceive of SD as development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). We understand this definition to encompass two kinds of claims (Voget-Kleschin, 2013):

- Direct claims for justice ask that all contemporary and future human beings should be able to live a decent human life.
- Indirect claims for justice encompass claims for a handling of our social and natural environment that qualifies as not undermining contemporary and future humans' ability to live such a decent human life.

Thus conceptualizing sustainability allows framing the above mentioned arguments: Positive health effects, positive equity effects as well as the economic benefits of reducing virtual land import can be framed as contributions towards meeting direct claims for justice. By contrast, a diminishment of productivity and competitiveness of European agriculture violates direct claims for justice. Similarly, environmental degradation and societal disturbance linked to virtual land ex- and imports violates indirect claims for justice. By contrast, ecological benefits correspond to demands for avoiding negative repercussions on our natural and social environment and thus to indirect claims for justice. In terms of our understanding of sustainability direct and indirect claims for justice are equally important and mutually constraining each other. This means that a certain process or measure, such as promotion of domestic protein crops or an expanded export strategy does only qualify as contributing to SD if it contributes to meeting direct and indirect claims for justice.

In the study we calculated a net import of virtual land associated with the current production and consumption patterns. Similar effects for Germany were also shown by Witzke, Noleppa, and Zhirkova (2011) and for Europe by Steger (2005) and Sleen (2009). To the best of our knowledge, this study is the first to link dietary recommendations and dietary styles with virtual land flows on the basis of a complete diet model. We propose a dietary regime allowing for a balanced trade of virtual land in Germany. Other studies with a similar scope focused either on the current nutrition regime and related environmental impacts in a particular country and abroad – for Switzerland Jungbluth, Nathani, Stucki, and Leuenberger (2011), for the Netherlands Gerbens-Leenes and Nonhebel (2005), for the Philippines Kastner and Nonhebel (2010) – or analysed additionally the possible effects of different dietary changes – for the EU Tukker et al. (2011), for the US-state New York Peters, Wilkins, and Fick (2007), for Germany Wiegmann, Eberle, Fritsche, and Hünecke (2005) and Meier and Christen (2013). In contrast to the study by Wiegmann et al. (2005), which is mainly based on environmental data from single-case studies (bottom-up), we could use statistically more reliable data from representative surveys (top-down).

In contrast to Meier and Christen (2012a,b, 2013) we were able to combine the production specific top-down data with representative and subgroup-specific intake data, which allowed for a more detailed assessment on the demand side. We show which population groups would have to adapt most to reach the land-balanced scenario in contrast to the dietary recommendations and dietary styles. Further, we included the last published data concerning food losses/wastage in the agri-food sector in Germany (Kranert et al., 2012) and investigated the corresponding impact on land requirements and the virtual land balance. Finally, we extended the diet model by adding further products (cocoa, coffee, green/black tea, herbal tea, wine) and provide detailed feed composition tables of related animal-based products (see supplementary material).

Materials and methods

Virtual land versus the concept of the Ecological Footprint (EF)

Methodologically this paper refers to the ́virtual land́ approach. Allan (1993, 1994) initially developed the concept of virtual inputs for water. The underlying concept is as follows: Any goods being produced require inputs (water, land etc.). The inputs used in production are considered as virtual inputs (virtual water, virtual land etc.). If the commodity is traded internationally, then the virtual input is also traded (Hoekstra, 2003; Witzke & Noleppa, 2012). This concept should be distinguished from that of the 'Ecological

Footprint' (Wackernagel, White, & Moran, 2004; Wackernagel et al., 2005). This methodology already includes an environmental impact assessment and uses a so-called 'global hectare' as a functional unit. This 'global hectare' is an aggregated impact indicator of various weighted inputs, therefore normally resulting in higher values than those of the 'virtual land' (Koellner & Sleen, 2011).

Methodological approach

The analytical part in this study is in line with the ISO standard 14040/14044 (2006) concerning an attributional life cycle assessment (LCA). In contrast to this standard we considered just one inventory indicator (land use) and did not perform an impact assessment. The following steps were completed: (i) goal and scope definition/system boundaries, (ii) life cycle inventory and (iii) life cycle interpretation. By using representative land use factors from environmental-economic accounts, the method can be described as an 'environmentally extended input–output LCA' (Suh, 2003, see also section 'land use factors' below).

Goal

The goal of the study was to propose a diet that would, on a macro level in Germany, result in a reduction of the net virtual land imports to zero. To this end we analysed different dietary scenarios and compared the corresponding land demands with the area that would allow a balanced trade of virtual land. In a further step, population subgroups were analysed according to gender and age groups to determine their specific impact. Finally we analysed the impact of avoidable food losses/wastage and its relevance achieving a balanced trade of virtual land.

Scope (system boundaries)

We considered the agricultural land required to produce crops for direct human consumption, as feed and for usage in industry and the energy sector. Furthermore, we considered the area needed to produce the commodities' packaging material. The area demand of other activities in the agri-food sector (bedding, housing, manufacturing, trade) as well as in the consumption and waste stage of the products (dining-related space, sewage plants) were omitted due to data gaps and a presumably negligible share in the whole life cycle. Concerning aquatic foods (fish, shrimps, algae etc.) solely the land requirements of terrestrial feeds used in aquaculture production (mainly grains, soy) were taken into account.

Functional unit

On the product level, the functional unit refers to the area needed to produce 1 kg of product. On the diet level, the functional unit refers to a diet with an energy uptake of 2121 kcal person^{-1} day^{-1}. This energy uptake was calculated as weighted average mean based on the average energy uptake of men with 2413 person^{-1} day^{-1} and women with 1833 person^{-1} day^{-1} in the age of 14–80 years (MRI, 2008).

Allocation

In accordance with the ISO standard 14040/14044 (2006), in the case of co-product splitting (milk/meat, rapeseed oil/cake, sugar/molasses, etc.) we have applied an allocation based on the products' mass.

Life cycle inventory, intake and supply data

We analysed the inventory indicator land use, distinguishing between seven terrestrial land use categories: arable land (domestic/abroad), pastures (domestic/abroad), permanent culture (domestic/abroad) and forest (wood production for pallets, paper production for packaging material). Area requirements related to aquatic precincts (freshwater, marine water) were not considered in the study. To determine the land demand of complete diets corresponding intake amounts were decomposed to the level of 23 main ingredients (food groups). These main ingredients were adjusted by related supply amounts, documented in official food balance sheets, and linked to commodity specific land use factors. A detailed description of this approach and the algorithm applied can be found in Meier and Christen (2013). Data concerning the supply/consumption amounts, the energy content and related data sources are provided in the supplementary material. In comparison to Meier and Christen (2012a,b, 2013) the scope of the analysed products was extended by five stimulants (cocoa, coffee, black/green tea, herbal tea, wine) to cover whole diets more realistically.

Adjustment of the food groups analysed

In the assessment 42 different commodities were considered: 10 animal-based foods, 14 plant-based foods and 18 feeds (Table 1). To enable a comparison of the diets in 2006 and in 1985–1989 with dietary recommendations (Table 2), these were aggregated into the following 23 food groups (Table 3): dairy products (including butter, high-fat dairy products like cheese and cream, and low-fat dairy products like milk and yoghurt), meat products (including pork, beef/veal, poultry, other meat), egg products, fish/shellfish products, grain products, vegetables, legumes, vegan milk products, fruits, nuts and seeds, potato products, vegetal oils/margarine and sugar. Although entries concerning alcoholic beverages (beer, wine, spirits) as well as coffee, tea and cocoa do not exist in most of the recommendations and diets, these product groups were additionally considered.

As far as statistically reliable information about the composition of heterogeneous and complex food groups in the National Nutrition Surveys was available, the related food groups were taken apart and the raw products reallocated to the corresponding main group. This taking apart and reallocation was done in the case of grain products, vegetal oils/margarine, sugar/sweets as well as of drinks (beer, soft drinks, juices). To give an example: Besides bread and pasta, grain products include pastries and sweet bakery products (and therefore sugar). In the year 2005/2006, to produce a total of 8585 kt grain products 524 kt sugar was also used (BMELV, 2009). In the mass flow matrix which underlies this study, these 524 kt were taken from the grain products group and reallocated to the product group 'sugar, sweets'. Limitations are caused by ingredients for which no statistically reliable information was available (e.g., nut/seed usage in sweet bakery production).

Food losses, food wastage

In the literature 'food losses' refer to spoilage and weight losses on the producer level (on the farm and food industry level). To relate to retailers' and consumers' behaviour, corresponding food losses at these stages in the supply chain are denominated as 'food wastage'. Further a distinction between avoidable and not-avoidable food losses/wastage can be made (FAO, 2011; Lundquist, de Fraiture, & Molden, 2008; Parfitt, Barthel, & Macnaughton, 2010). To analyse the land savings of avoidable food losses/wastage we used the last published data for the German agri-food sector (Kranert et al. 2012). Although food losses on farm level were not considered due to lacks of statistical data, Kranert et al. (2012)

Table 1
Degree of self-sufficiency and land use factors.

		Degree of self-sufficiency in %	Land use factor (production + packaging) in $m^2\ kg^{-1}$	Data sources (production)	Comments
Animal-based foods					
Dairy products (fresh weight)	Butter	81	20.68	1)	Fat 83%, protein 0.8% BLE (2010)
	Cheese, curd	117	9.89	1)	Fat 18%, protein 22% BLE (2010)
	Creamy products	131	3.08	1)	Fat 7%, protein 5% BLE (2010)
	Whole milk	116	1.69	1)	FPCM[a], fat 3.5%, protein 3.3% BLE (2010)
Meat products	Beef, veal	126	25.44	1)	Carcass weight
	Pork	96	8.91	1)	Carcass weight
	Poultry	86	6.24	1)	Carcass weight
	Other meat	61	19.92	1)	Carcass weight, consisting of meat from sheep, goat, horse, deer etc.
	Fish, shellfish	25	0.17	2)	Ex harbour. consisting of 48% pollack (Pollachius pollachius), 23% herring (Clupea harengus), 21% trout/salmon (Salmonidae from aquaculture), 8% shrimp/prawns (Crustaceae), BLE (2009)
	Eggs	71	3.80	1)	Heńs eggs, shell weight
Plant-based foods					
	Grain products	109	1.78	3)	Fresh weight
	Vegetables	36	0.45	3), 4)	Fresh weight, consisting of 36% domestically produced vegetables, 64% imported vegetables
	Legumes	96	2.11	3)	Fresh weight
	Vegan milk products	36	0.71	4)	Fresh weight, soy milk (fat 2.2%, protein 3.7%) according to Birgersson, Karlsson, and Söderlund (2009)
	Fruits	11	0.86	3), 4)	Fresh weight, consisting of 11% domestically produced fruits, 37% imported citrus fruits, 52% other imported fruits
	Nuts, seeds	9	2.91	3), 4)	Dry weight, consisting of 29% groundnuts, 24% almonds, 16% hazelnuts, 9% sunflower seeds, 9% walnuts, 6% pistachios, 7% other nuts FAO Stat (2012)
	Potato products	137	0.30	3)	Fresh weight
	Vegetal oils, margarine	30	4.14	3), 4)	Consisting of 31% soy oil, 28% rapeseed oil, 19% sunflower oil, 18% palm fat, 4% other oil FAO Stat (2012)
	Sugar	136	1.15	3)	Dry weight, sugar from sugar beet
Stimulants	Cocoa	0	25.49	4)	Dry weight
	Coffee	0	10.68	4)	Roasted, dry weight
	Tea (black, green)	0	8.19	4)	Dry weight
	Herbal tea	54	6.11	3)	Dry weight
	Wine	45	1.60	3), 4)	Fresh weight
Feeds (fresh weight)					
	Wheat	94	1.51	1)	
	Rye	93	2.33		
	Barley	97	1.96		
	Oats	95	2.20		
	Maize (corn)	84	1.38		
	Other grains	97	2.02		
	Pulses	100	4.57		
	Rape cake	114	3.42		
	Soy cake	0	4.26		
	Palm cake	0	1.68		
	Other oil crops	29	5.61		
	Soy oil	0	4.26		
	DDGS	26	1.38		
	Potatoes, pulp	100	0.29		
	Molasses, sugar	100	0.19		
	Other root crops	100	0.07		
	Roughages (arable land)	100	0.47		
	Roughages (grassland)	100	0.53		

Highlighted in grey: Foods/feeds with a degree of self-suffociency far below 100%.
1) For documentation of the feed composition of animal-based foods due to animal species see the supplemental material.
2) Of land use relevance are solely Salmonidae products from aquaculture, which receive a plant-based diet according to Nielsen et al. (2003).
3) Schmidt and Osterburg (2010)
4) FAO Stat (2012)

Table 2
Dietary recommendations and dietary styles analysed.

	Description	Reference
Dietary recommendations	D-A-CH (official nutrition recommendations for Germany, Austria and Switzerland)	DGE (2008), SGE (2012)
	UGB (alternative recommendations by the Federation for Independent Health Consultation with less meat, but more legumes and vegetables)	UGB (2011)
Dietary styles	Ovo-lacto-vegetarian (plant-based diet with egg and milk products, without meat and fish)	USDA, USDHHS (2010)
	Vegan (totally plant-based diet, without meat, milk, fish and egg products and instead more fortified soy-based milk products, more legumes, nuts and seeds	USDA, USDHHS (2010)

distinguished between food losses in the food industry as well as food wastage in the retail and catering sector and on household level.

Imports, exports and degree of self-sufficiency

Due to the manifold trade relations of the German agri-food sector it was impossible to include all imports and exports, including their related virtual land flows, in the assessment. Nevertheless, to deal with this issue in a pragmatic manner we used origin-specific production data from FAO Stat (2012) for the year 2003 for commodities where the degree of self-sufficiency is far below 100% (highlighted in grey in Table 1). The land use factors shown were calculated as weighted average means using the corresponding degree of self-sufficiency and related yields in domestic and/or foreign production. Although self-sufficiency for butter and egg products is also below 100%, we did 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 and the composition of fish feed we used the Danish LCA Food database (Nielsen, Nielsen, Weidema, Dalgaard, & Halberg 2003). The low self-sufficiency for oil cakes (mainly from soy and palm fruit) is considered indirectly in the feed compositions and thus influences the net trade balance of livestock products.

Land use factors

Based on the aforementioned points, related agrarian raw products were converted into the area needed to produce them. For German production, data were provided by the *System of Environmental and Economic Accounting* (SEEA, Schmidt & Osterburg, 2010). Yields of imported products were provided according to origin mainly by FAO Stat (2012) (for exceptions see details in Table 1). The reference year for both data sets was 2003. Concerning German production, both data sets are comparable as they are based on the *Farm Accountancy Data Network* (FADN). For all European countries the FADN represents the main data compiler of agricultural statistics. The land use factors of animal-derived foods were based on the feed composition data in Leip et al. (2010) – see supplementary material.

Table 1 gives an overview of the product groups analysed, the degree of self-sufficiency and related land use factors.

Intake data for the year 2006, for 1985–89 and for the nutrition scenarios

Nutritional intake data for the years 1985–89 and the year 2006 were provided by the two National Nutrition Surveys, NNS I and NNS II (Kübler, Balzter, Grimm, Schek, & Schneider, 1997; MRI, 2008). Whereas the NNS I (1985–89) is based on a sample size of 25,000 persons (4–94 years) in the former Federal Republic of West Germany, the NNS II (2006) is based on a sample size of 19,000 persons (14–80 years) in the whole reunified Germany. While the NNS I was representative of 59 million people, the NNS II is representative of 68 million people, or 83% of the total population. In this paper we focused on the results of the NNS II, but also refer to the NNS I for comparative purposes.

In the scenario analysis we compared the average nutrition pattern in the year 2006 with dietary recommendations and diet styles. The following quantifiable food-related dietary profiles were examined (Table 2). In contrast to nutrient-based dietary recommendations (NBDR), food-based dietary recommendations (FBDR) are more consumer-friendly and could be, if sufficiently determined (comprehensive, consistent and standardized product categories), compared and analysed from a virtual land flow perspective. Moreover FBDRs claim to be “developed in a specific sociocultural context, and [therefore] need to reflect relevant social, economic, agricultural and environmental factors affecting food availability and eating patterns.” (FAO, 1996).

Most of these recommendations do not feature entries concerning alcoholic beverages (beer, wine, spirits) as well as coffee, tea and cocoa. The DGE (2008) and USDA, USDHHS (2010) define an upper intake level of 10–20 g alcohol or 1–2 drinks person^{-1} day^{-1}, respectively. In terms of wine this would result in an amount of 125–250 grams person^{-1} day^{-1}. As this is a recommendation for an upper intake level, deducing an average recommended level is arbitrary. To circumvent this discussion, we included wine (as source of alcohol) and the other stimulants in the analysis of the nutrition scenarios, assuming the same intake amounts of these products as for the intake in the year 2006. With an average intake of 39 grams wine person^{-1} day^{-1} this is a very conservative interpretation of the corresponding recommendation. Table 3 gives an overview of the intake amounts analysed based on 2121 kcal person^{-1} day^{-1}. For meat products in the scenarios of D-A-CH and UGB, we assumed the same composition according to animal species as in the year 2006. Although all diets and dietary scenarios were based on an average daily supply of 2121 kcal p^{-1}, the total weight of the products varies considerably. In the case of the ovo-lacto-vegetarian and vegan diet, these differences are mainly due to the fact that the entry for milk and vegan milk products in USDA, USDHHS (2010) refers to (vegan) milk equivalents. A generally higher intake in the scenarios is also due to a higher intake of vegetables and legumes. In comparison to 2006, the intake of fruits in the scenarios is reduced. Intake amounts for juices, soft drinks and beer, which contain the fruit and sugar products considered as well as barley (for beer production), were reallocated to the corresponding group. Hops used in beer production were omitted from the assessment.

Determining a diet with a zero land balance

To determine the nutrition-related area that would ensure a balanced trade of virtual land (zero balance), we subtracted the observed imports from the land demand in the year 2006 and then

Table 3
Intake amounts analysed, based on the average diet with 2,121 kcal person^{-1} day^{-1}.

	Intake 1985–89 mean		Intake 2006 mean		D-A-CH		UGB		Ovo-lacto vegetarian		Vegan	
	g (kcal) person^{-1} day^{-1}											
Butter	20	(155)	13	(97)	12	(88)	10	(79)	8	(63)	–	–
High-fat milk products (cheese, cream)	40	(163)	48	(194)	57	(233)	78	(155)	655	(426)[a]	–	–
Low-fat milk products (milk, yoghurt)	177	(144)	214	(189)	235	(139)	391	(231)			–	–
Meat products[b]	165	(238)	109	(159)	67	(88)	42	(55)	–	–	–	–
Beef, veal	43	(45)	20	(21)	12	(16)	8	(10)	–	–	–	–
Pork	97	(160)	60	(100)	37	(48)	23	(30)	–	–	–	–
Poultry	22	(29)	26	(34)	16	(21)	10	(13)	–	–	–	–
Other meat	3	(5)	3	(4)	2	(2)	1	(1)	–	–	–	–
Fish, shellfish	17	(18)	26	(26)	28	(28)	26	(26)	–	–	–	–
Egg products	32	(46)	19	(27)	10	(14)	10	(14)	17	(24)	–	–
Grains	305	(731)	293	(702)	378	(851)	421	(766)	381	(694)	381	(694)
Vegetables	152	(40)	236	(61)	417	(109)	521	(136)	255	(67)	255	(67)
Legumes[c]	–	–	–	–	–	–	54	(75)	130	(182)	134	(188)
Vegan milk products[d]	–	–	–	–	–	–	–	–	–	–	758	(426)
Fruits	140	(65)	353	(163)	261	(120)	209	(96)	261	(120)	261	(120)
Nuts, seeds[e]	2	(6)	4	(11)	–	–	–	–	22	(67)	27	(85)
Potato products	113	(78)	84	(58)	117	(81)	85	(59)	112	(77)	112	(77)
Vegetal oils, margarine	23	(204)	16	(140)	25	(218)	31	(276)	28	(248)	35	(312)
Sugar	50	(188)	67	(238)	27	(97)	27	(97)	27	(97)	27	(97)
Cocoa	2.7	(12)	4.8	(21)	4.8	(21)	4.8	(21)	4.8	(21)	4.8	(21)
Coffee	11	(5)	14	(6)	14	(6)	14	(6)	14	(6)	14	(6)
Tea (black, green)	0.3	(0.1)	1.9	(0.6)	1.9	(0.6)	1.9	(0.6)	1.9	(0.6)	1.9	(0.6)
Herbal tea	0.3	(0.1)	1.9	(0.6)	1.9	(0.6)	1.9	(0.6)	1.9	(0.6)	1.9	(0.6)
Wine	43	(30)	39	(27)	39	(27)	39	(27)	39	(27)	39	(27)
Sum	1294	(2121)	1542	(2121)	1694	(2121)	1968	(2121)	1958	(2121)	2053	(2121)

D-A-CH: official recommendations in Germany (D), Austria (A) and Switzerland (CH) (DGE, 2008).
UGB: alternative recommendations of the Federation for Independent Health Consultation (UGB, 2011).
[a] In whole milk equivalents (FPCM, fat 3.5%, protein 3.3%).
[b] As the recommendations of D-A-CH & UGB recommend low-fat meat products a reduced energy content of 131 kcal 100 g^{-1} product was assumed.
[c] If not indicated legumes are subsumed under vegetables.
[d] In soya milk equivalents (fat 2.2%, protein 3.7%).
[e] D-A-CH and UGB do not have quantifiable recommendations for nuts and seeds.

added the observed exports. Concerning imports, commodities with a non-nutritional purpose (industry, energy sector) were considered separately. The following algorithm was applied.

$$\mathrm{Area}_{ZLB} = \mathrm{area}_{\mathrm{intake}\ 2006} - \mathrm{area}_{\mathrm{imports}\ 2006(\mathrm{food,feed})} - \mathrm{area}_{\mathrm{imports(industry,energy)}} + \mathrm{area}_{\mathrm{exports2006}} \quad (1)$$

Area_{ZLB}: Nutritional land demand with a zero land balance.
$\mathrm{Area}_{\mathrm{intake}\ 2006}$ = Area needed for nutritional purposes in 2006.
$\mathrm{Area}_{\mathrm{imports}\ 2006\ (\mathrm{food,\ feed})}$ = Area needed abroad for nutritional purposes in 2006.
$\mathrm{Area}_{\mathrm{imports}\ (\mathrm{industry,\ energy})}$ = Area needed abroad for non-nutritional purposes in 2006.
$\mathrm{Area}_{\mathrm{exports}\ 2006}$ = Area domestically used for exports in 2006.

Results

Figure 1 gives an overview of the considered land use and land use flows relating to the German agri-food sector in the year 2006. The total human consumption leads to an area use of 194,600 km^2, mainly due to the consumption of animal-based foods like meat and dairy products (69%). The consumption of plant-based products accounted for 31% of the area needed. The industry and energy sectors depended on 19,800 km^2. Taking all net trade flows together they result in a virtual land import of 64,100 km^2 and a virtual land export of 21,600 km^2. From the perspective of virtual land imports it is necessary to distinguish between land imports for human consumption via plant-based and animal-based products (accounting for 58,200 km^2) and land imports for the industry and energy sectors (accounting for 5900 km^2). If both these virtual import flows are considered and the virtual land export subtracted, the net balance of the German agri-food sector results in an area of 42,500 km^2 of land that was virtually imported as a result of domestic consumption.

The virtual land imports are related to following commodities: feed (37% – incl. 29% for soy-derived products, 1% for palm cake, 7% for other feed), vegetal oils/fats (21% – incl. 7% for soy oil, 5% for rape oil, 3% for palm oil, 6% for other oil), fruits (13%), cocoa (10%), coffee (8%), vegetables (4%), wine (3%), nuts/seeds (1%) and other products (3%). Imported and domestically consumed soy products accounted for 36% of all imports alone, corresponding to a land use of 22,900 km^2 or 278 m^2 p^{-1} a^{-1} (82% as soy cake and oil as feed and 18% as oil for human consumption).

The virtual net land exports were composed of grain products (62%), milk products (17%), meat products (10%), sugar (8%) and other products (3%).

Feed export accounts for a virtual land export of 2900 km^2 (Fig. 1). This number is based on the official feed statistics for the year 2006 (BMELV, 2009). Nevertheless it could not be ruled out that commodities considered in the main export flow may also be used as feed in foreign countries.

A balanced diet in comparison with nutrition scenarios

Figure 2 gives an overview of the aforementioned land use and land use flows in the year 2006 in comparison with the land demand of the nutrition scenarios analysed. To determine the nutrition-related area necessary to ensure a balanced trade of virtual land, the land demand of the intake in the year 2006 was adjusted based on the observed imports and exports. Regarding imports, commodities with a non-nutritional purpose (for the industry and energy sectors) were considered separately (formula (1)).

The resulting area of 152,100 km^2 represents the nutrition-related land demand that would allow a balanced trade of virtual land. Compared with the nutrition scenarios, the diet closest to this boundary would be a diet in between the recommendation of the UGB and an ovo-lacto-vegetarian one. A diet in accordance with the recommendations of D-A-CH would result in a higher land demand. Just an ovo-lacto-vegetarian and in particular a vegan diet would result in a positive land balance, leading to domestic net land savings.

Is such a diet achievable?

To answer the question of whether shifting an entire country's population to a diet with an equated land balance is achievable, we analysed food and beverage intake in the years 1985–89 equally from a land use perspective. Levelled on the average energy intake of 2121 kcal p^{-1} d^{-1}, which was also applied for the year 2006 and in the scenarios, we calculated an average nutrition-induced land demand of 2686 m^2 p^{-1} a^{-1}. That is 320 m^2 or 14% higher than the land use of the average diet in the year 2006 (Fig. 3). As Fig. 4 shows, this decline is mainly due to a decreased consumption of beef and veal compared to 1985–89. This decrease was partly compensated by an increase in the consumption of dairy products, fruits, vegetables and grain products as well as cocoa and wine.

For the conversion of the consumed products into land-equivalents we assumed the same land use factors and degrees of self-sufficiency as were used for the year 2006 (Table 1). Taking yield gains and a rise in production efficiencies within the last 20 years in the German agricultural sector into consideration, the land demand for nutrition in the years 1985–89 could be even higher. Nevertheless, the effects of efficiency improvements have not been analysed in this study.

Summarised, the results show that within 20 years a shift in the average diet led to a significantly lower land demand of at least 14%. To achieve the nutrition-related land demand which would ensure a balanced trade flow of virtual land, a further reduction of 22% would be necessary (from 2365 m^2 p^{-1} a^{-1} to 1848 m^2 p^{-1} a^{-1}, Fig. 3) Taking dietary developments within the last 20 years into account, we argue that such a shift is possible. The main questions arising from this reduction gap are as follows:

(1) Which population groups would need to change their nutrition most to reach a diet that would allow an equated land balance?
(2) Could an equated land balance also be reached by taking possible food waste reductions into account?
(3) Which measures would be applicable to reach the aspired goal more quickly?

The first and the second question will be answered in the following. Answering the third question was not part of this study, but this topic and related implications will be briefly addressed in the conclusions.

Population groups

For this working step we used subgroup-specific intake data from the National Nutrition Survey II (NNSII, MRI, 2008) and analysed the related land demand with the same method. The only difference was that we used age group-specific energy intakes on the basis of the documented intake amounts. The related land use in the year 2006 was compared with the related ones of the dietary recommendations (D-A-CH, UGB) and dietary styles (ovo-lacto-vegetarian, vegan). In another step the results were extrapolated on a national level based on the population in the corresponding age groups in the year 2006 (Destatis, 2007). The distribution of the age groups was provided by the NNS II (MRI, 2008). In Table 4 and Fig. 5 we show the land area that would be freed up if the nutritional behaviour in the age groups would be in accordance with the official recommendations or diet styles. Here, it is

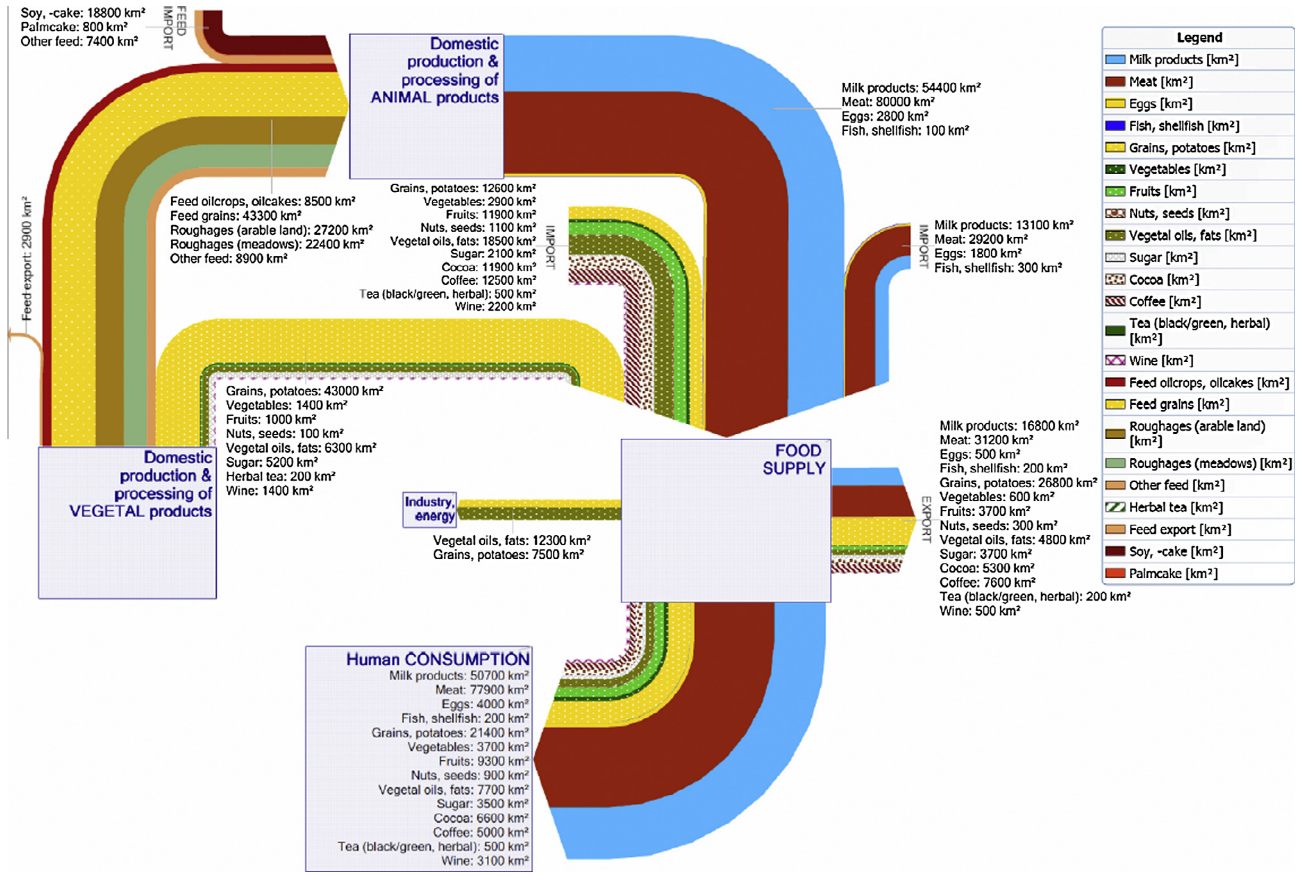

Fig. 1. Land use of Germany's food supply in the year 2006 (in km^2).

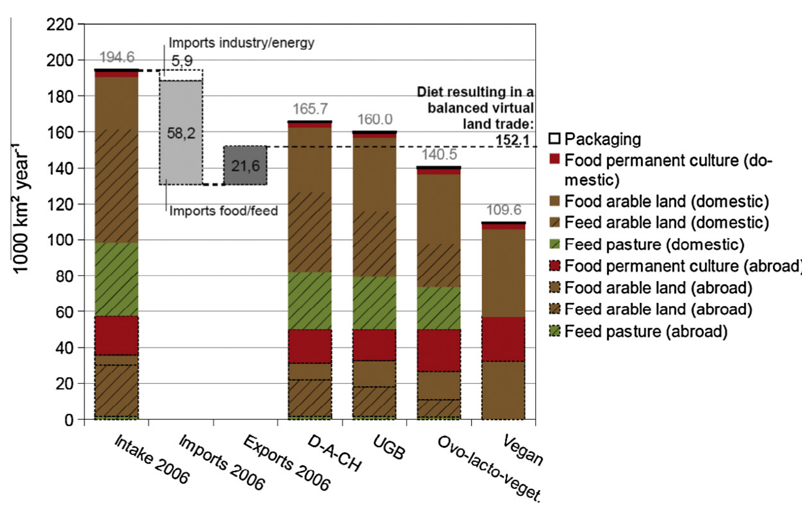

Fig. 2. Nutrition-related land demand of the intake in 2006 and of different dietary scenarios (incl. the area with a zero land balance) according to land use types.

necessary to bear in mind that the age span analysed (14–80 yrs) represents just 83% of the total population. Therefore the sum of the potential land savings is lower than in Fig. 2. As the intake of cocoa, coffee, tea and wine was assumed to be the same in the scenarios as in the year 2006, related entries do not appear in Fig. 5. For meat products, the same composition according to animal species was assumed in the scenarios as in the year 2006.

The results show that in all scenarios the highest land-saving potentials exist by shifting the average diets of younger and middle-aged men. Compared across all age groups, men's land-saving potentials are roughly twice as high as women's.

The role of food losses/wastage

For answering the question whether possible food waste reductions would be sufficient to balance Germany's trade of virtual land, we used data from Kranert et al. (2012). Based on a comprehensive data analysis of the German agri-food sector Kranert et al. (2012) calculated per person and year an avoidable amount of food losses/wastage of 105.3 kg – including 22.5 kg in the food industry, 6.7 kg in the retail sector, 23.1 kg in the catering sector and 53.1 kg on household level. Applying this data and corresponding land requirements to the scenarios analysed in this study the diet re-

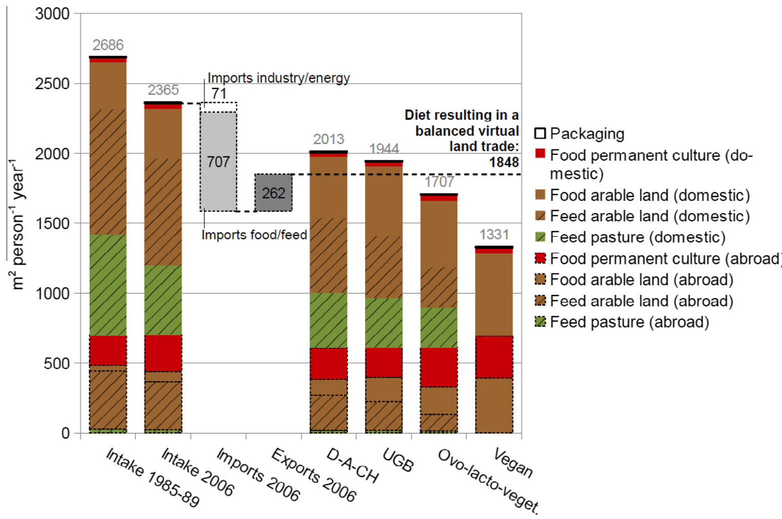

Fig. 3. Nutrition-related land demand of the intake in 1985–89, 2006 and of different dietary scenarios according to land use types.

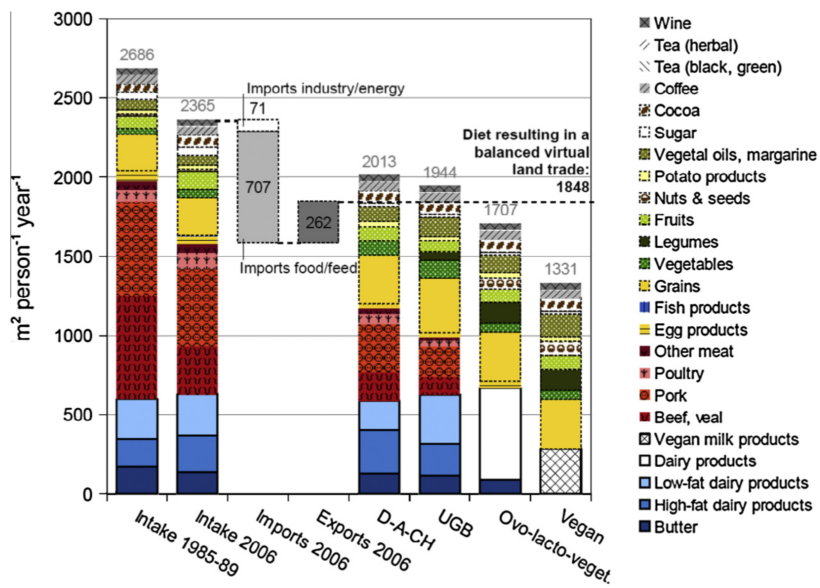

Fig. 4. Nutrition-related land demand of the intake in 1985–89, 2006 and of different dietary scenarios according to food groups.

lated land demand would decrease by 13% – intake 2006: from 2365 to 2059 $m^2\,p^{-1}\,a^{-1}$, D-A-CH: from 2013 to 1753 $m^2\,p^{-1}\,a^{-1}$, UGB: from 1944 to 1693 $m^2\,p^{-1}\,a^{-1}$, ovo-lacto-vegetarian: from 1707 to 1486 $m^2\,p^{-1}\,a^{-1}$, vegan: from 1331 to 1158 $m^2\,p^{-1}\,a^{-1}$.

The results show, taking possible land savings by reduced food losses/wastage into account, that besides the ovo-lacto-vegetarian and vegan diet also the recommendations of D-A-CH and UGB would lead to a positive virtual land balance. A reduction of food losses/wastage, regarding the average nutrition in the year 2006 (scenario 'intake 2006') with 2059 $m^2\,p^{-1}\,a^{-1}$, would not be enough to reach the goal of 1848 $m^2\,p^{-1}\,a^{-1}$, a diet resulting in a balanced trade of virtual land.

Discussion

In this study national and international land use statistics were combined with representative trade and consumption data relating to the German agri-food sector as well as representative subgroup-specific intake data in the year 2006. In this section we compare our results with the outcomes of other studies and discuss the limitations of the method applied.

Comparison to other studies

Taking different approaches, reference years and reference countries into consideration, our results are comparable to those from other, similar studies. Wiegmann et al. (2005) calculated an average land demand of nutrition in Germany in the year 2000 to be 2396 $m^2\,p^{-1}\,a^{-1}$. The difference to the 2365 $m^2\,p^{-1}\,a^{-1}$ we determined could be explained by the fact that Wiegmann et al. used different production data (referring to the years 1990–2000), their reference year was 2000 and the approach was a classical bottom-up LCA. A distinction between foreign and domestic land use was not made.

On a three-year basis (2008–10) Witzke et al. (2011) calculated a virtual land import of 79,700 $km^2\,a^{-1}$ for Germany, including

Table 4
Energy intake, land use and related land savings in population groups.

				Men						Women		
Age group		14-18	19-34	35-50	51-64	65-80		14-18	19-34	35-50	51-64	65-80
Energy intake	kcal p^{-1} d^{-1}	2705	2643	2477	2252	2056		2018	1932	1865	1777	1678
Population 2006	in million	2.4	7.9	10.9	6.9	5.9		2.3	7.6	10.4	7.0	7.1
Land use and land saving potentials												
Intake 2006	m^2 p^{-1} a^{-1}	3037	3061	2792	2509	2247		2012	1959	1944	1875	1758
land	km^2 a^{-1}	7200	24,100	30,400	17,300	13,200		4500	15,000	20,300	13,100	12,500
use	km^2 a^{-1}			92,300						65,500		
	km^2 a^{-1}						157,800					
D-A-CH	m^2 p^{-1} a^{-1}	2515	2460	2314	2115	1942		1908	1832	1773	1696	1609
land	km^2 a^{-1}	6000	19,400	25,200	14,600	11,400		4300	14,000	18,500	11,900	11,500
use	km^2 a^{-1}			76,600						60,200		
	km^2 a^{-1}						136,800					
Saving in comparison to intake 2006	km^2 a^{-1}			-15,700						-5300		
	km^2 a^{-1}						-21,000					
	in %						***-13.3%***					
UGB	m^2 p^{-1} a^{-1}	2427	2374	2233	2042	1876		1843	1770	1713	1639	1555
land	km^2 a^{-1}	5800	18,700	24,300	14,100	11,000		4200	13,500	17,900	11,500	11,100
use	km^2 a^{-1}			73,900						58,200		
	km^2 a^{-1}						132,100					
Saving in comparison to intake 2006	km^2 a^{-1}			-18,400						-7300		
	km^2 a^{-1}						-25,700					
	in %						***-16.3%***					
Ovo-lacto-	m^2 p^{-1} a^{-1}	2000	1957	1843	1688	1553		1527	1468	1422	1361	1293
vegetarian land	km^2 a^{-1}	4700	15,400	20,100	11,700	9100		3400	11,200	14,800	9500	9200
use	km^2 a^{-1}			61,100						42,138		
	km^2 a^{-1}						109,300					
Saving in comparison to intake 2006	km^2 a^{-1}			-31,200						-17,200		
	km^2 a^{-1}						-48,500					
	in %						***-30.7%***					
Vegan	m^2 p^{-1} a^{-1}	1572	1539	1452	1334	1230		1210	1165	1130	1083	1032
land	km^2 a^{-1}	3700	12,100	15,800	9200	7200		2700	8900	11,800	7600	7300
use	km^2 a^{-1}			48,100						38,400		
	km^2 a^{-1}						86,500					
Saving in comparison to intake 2006	km^2 a^{-1}			-44,200						-27,100		
	km^2 a^{-1}						-71,300					
	in %						***-45.2%***					
Land saving that would result from a diet with an equated land balance	in %						***-21.8%***					

25,800 km^2 for soy products, 11,200 km^2 for cocoa, 10,800 km^2 for coffee, 1900 km^2 for cotton and 400 km^2 for tobacco. Besides the fact that in our study cotton and tobacco were not considered, the difference compared to 64,100 km^2 – the virtual land import that we determined in this study – could be explained by a smaller area needed to produce the domestically consumed soy products (22,700 km^2), cocoa (6600 km^2) and coffee (5000 km^2) as well as different reference years. An increased import of virtual land in 2008–10 might be attributable to the fact that in recent years Germany's production capacities for meat products have been successively expanded (with an increased demand for feeds). In 2006 the supply of meat products reached a self-sufficiency level of 100% for the first time since 1961. From this point onwards production and export capacities were expanded continuously, amounting up to a degree of self-sufficiency of 113% in the last documented year 2010 (BMELV, 2011; FAO Stat, 2012). On an individual level, for meat consumption in the years 2008–10 Witzke et al. (2011) calculated a land use of 1,030 m^2 p^{-1} a^{-1}. Taking only meat products into account we calculated 953 m^2 p^{-1} a^{-1} for the year 2006. This difference could be explained by a slightly higher consumption of

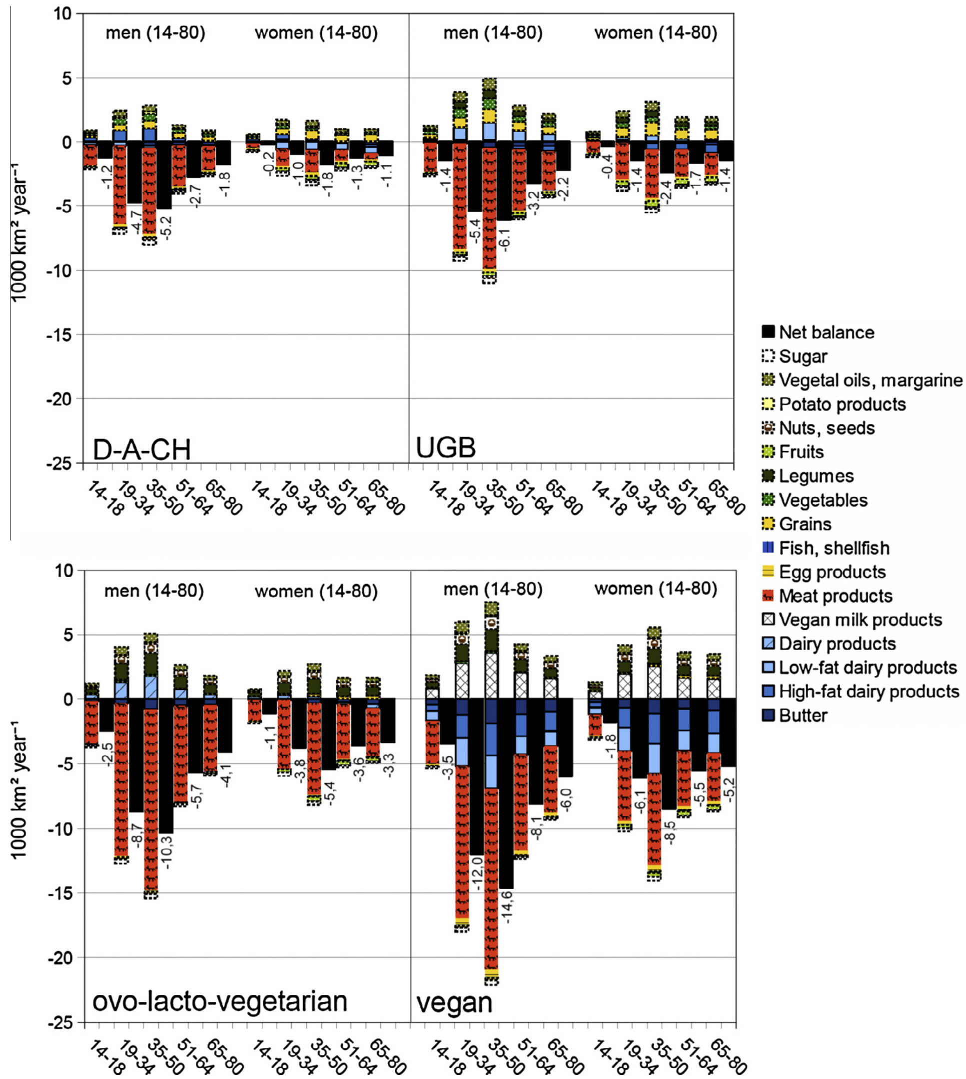

Fig. 5. Land savings of the dietary recommendations (D-A-CH, UGB) and dietary styles (ovo-lacto-vegetarian, vegan) in comparison to the intake in the year 2006 according to product and population groups.

meat-based products in the years 2008–10 (average: 88 kg p^{-1} a^{-1}) than 2006 (86 kg p^{-1} a^{-1}) and different land use factors.

Similar studies, but with different reference countries, show comparable results. Peters et al. (2007) analysed the land requirements for 42 different diets in the US state New York, whereby the area ranged from 1800 m^2 to 8,600 m^2 p^{-1} a^{-1}, depending on the consumption of meat and eggs as well as calories from fat. Gerbens-Leenes and Nonhebel (2005) calculated a nutrition-related land use of 1909 m^2 p^{-1} a^{-1} in 1990 for an average citizen in the Netherlands, but did not distinguish between different land types and origins. On a product level, a comparison with the meta-analysis from Vries and Boer (2010) shows a strong concordance for all animal-based products. Only the land use factor for egg products used in this study, at 3.8 m^2 kg^{-1}, is lower than the range indicated by Vries & Boer, which varies from 4.5 to 7.8 m^2 kg^{-1}.

Limitations

Limitations in this study are mainly due to the attributional approach applied and the underlying production data. Land use as an environmental indicator was handled as a normal inventory indicator in an LCA (life cycle assessment). LCAs can be elaborated either by an attributional or a consequential approach (Earles & Halog, 2011; Ekvall & Weidema, 2004). Whereas attributional LCAs are suited to ex-post analysis, a consequential approach is more applicable for ex-ante studies (scenario analysis, forecast studies etc.). Therefore a consequential approach would be necessary to more realistically include possible trade-offs, market effects and interlinkages in the nutrition scenario analysis (D-A-CH, UGB, ovo-lacto-vegetarian, vegan). Thus our scenario analysis may have led to biased results.

Due to the manifold trade relations of the German agri-food sector it was impossible to include all imports and exports and their related virtual land flows in the assessment. Nevertheless, to approach this issue in a practical manner we used origin-specific production data from FAO Stat (2012) for the year 2003 for commodities where the degree of self-sufficiency is far below 100%. For the land use of fish produced in aquaculture we relied on the LCA Food database (Nielsen et al., 2003), which has been built following a consequential approach regarding system boundaries, allocation and data selection, whereas our study followed an attributional approach.

Concerning the allocation of milk and dairy products, it is favourable to include carbohydrates and other components in the allocation of the distinct products, in order to conduct the allocation on a dry mass basis (IFS, 2010; EPD, 2010). But from a statistical point of view sugar/carbohydrates contents are not available for all dairy products on national level (BLE, 2010). Therefore the allocation applied in this study was conducted according to the monitored fat and protein content of the different dairy products. A detailed description of this method can be found in Meier and Christen (2012a).

Although different intake, consumption and supply data were used, for the years 1985–1989 the same production conditions (and therefore production efficiencies) as well as the same import shares and import countries were assumed as for the year 2006. Furthermore, it must be recalled that the basic population of both National Nutrition Surveys (NNS) was adjusted to the same age group (14–80 years), but that the first NNS (1985–1989) was compiled in the former West Germany – with just 80% of the total German population (Destatis, 2007). Therefore the specificity of food consumption in the former East Germany was not considered in the comparison. Besides the fact that specific intake data for the East were not available, the official supply data vary depending on the food group considered. Whereas the consumption of animal-derived products (exception: fish) and margarine was almost equal, the consumption of grain products and potatoes was higher and the consumption of fruits was lower in the East. Nonetheless, due to methodological differences the comparability of the supply data of both countries is limited. Presumably the actual consumption of grain products and potatoes in the East was lower, since their usage as feed was included in the food consumption (Karg, Gedrich, & Steinel, 1996).

Nuts and seeds were omitted in the scenario analysis of the recommendations (D-A-CH, UGB), since related recommendations do not exist.

Besides dietary shifts a reduced land use in the year 2006 as compared to 1985–89 can be explained by further reasons: As described in Meier and Christen (2013) from a land use perspective alterations in food losses/wastage in 2006, as compared to 1985–89, were of minor relevance. Nevertheless, related effects were implicitly considered in this study. The impact of efficiency gains was not considered due to the challenging task of modelling properly the technical status of the agri-food sector in the years 1985–89. Therefore for the years 1985–89 the same production conditions were assumed as for the year 2006. Taking yield gains and a rise in production efficiencies within the last 20 years in the German agricultural sector into consideration, the land demand for the nutrition in the years 1985–89 could be even higher. A third driver might be due to demographical reasons. For the group of the 14–80 years-old, official demographical data show an arithmetic average age of 42.6 years in 1985–89 compared to 45.3 years in 2006 (Destatis, 2007). Thus, within 20 years the population grew roughly three years older. To what extent this influences the results was not quantified. If a declining intake of land use intensive products (mainly meat, dairy products) is assumed, this could lead to an overestimation of the achieved land use savings in 2006, compared to 1985–89.

Conclusions

In this study we show that in the year 2006 as a result of domestic consumption Germany virtually imported an additional area of 42,500 km^2, mainly used abroad for the production of soy based products, fruits, cocoa, coffee and vegetables. This roughly equals 30% of the agricultural area domestically available. As discussed in the introduction, such virtual land imports are strongly linked to negative social and environmental repercussions and thus violates claims for sustainable development (SD), namely indirect claims for justice. Accordingly, balancing virtual land trade contributes to SD. However, this only holds in so far as such balancing does not result in significant economic disadvantages which could be conceived as violating direct claims for justice. In this regard, we presented different strategies for coping with virtual land imports, import dependency and export competitiveness. We demonstrated that a diet shift allows achieving the ecological benefits of a protein crop strategy such as less virtual land imports and a stronger pronunciation of protein plants in the domestic crop rotation while concurrently maintaining or even expanding export competitiveness. Furthermore, such a dietary shift would be mostly in accordance with recommendations, and would therefore lead to public health gains (though this was not considered explicitly in the study). Such health benefits can in turn be conceived as a further contribution towards meeting direct claims for justice. We show further that a reduction of avoidable food losses/wastage would not be sufficient to level out the virtual land balance of the average nutrition in Germany. We therefore conclude that a combination of all measures – the promotion of the domestic production of leguminous protein plants, a broader encouragement of consumers to increase consumption of plant protein while decreasing consumption of animal protein as well as a stronger effort to decrease food losses/wastage - constitutes a valuable and necessary contribution towards more sustainable food production and consumption.

However, we need to highlight two important caveats:

First, an evaluation from a sustainability perspective needs to take into account how a dietary shift could be institutionally implemented (Eyles, Ni Mhurchu, Nghiem, Blakely, & Stuckler, 2012; Reisch, Lorek, & Bietz, 2011). Instruments that directly or indirectly increase prices of animal products could be especially effective (Caraher & Cowburn, 2005; Schösler, de Boer, & Boersema, 2012; Wirsenius, Hedenus, & Mohlin, 2011). However, there is still need for comprehensive research about combinations, legitimacy and design of such measurements (Cash & Lacanilao, 2007; Dellava, Bulik, & Popkin, 2010; Mytton, Clarke, & Rayner, 2012). With regard to consumer groups, the largest environmental benefits expected would result in altered consumption patterns mainly of younger and middle-aged men. Nevertheless, women's land saving potentials should not be ignored neither. In further studies, it may be of interest to investigate which instruments are most applicable for addressing individual consumer groups specifically. From a sustainability perspective, the issue of legitimacy is especially important, because to contribute to sustainable development measures aiming at dietary changes themselves need to avoid violating direct claims of justice (Voget-Kleschin, 2012, in press). This means they should allow citizens to participate in creating and shaping adequate policy measures.

Second, to set Germany's virtual import of land to zero, the consumption of imported stimulants, like cocoa, coffee, tea (FAO Stat, 2012), and wine would need to be taken into account. From a land use perspective, the consumption of cocoa and coffee products is most relevant. To level out the land balance using a diet based on the recommendations (D-A-CH, UGB), the consumption of stimulants and wine may have to be cut by half. In Germany, a positive virtual land balance would be reached if the population shifted to an ovo-lacto-vegetarian or a vegan diet (even if consumption of stimulants was maintained). Clinical studies have shown that with a well-balanced ovo-lacto vegetarian diet no adverse public health effects are expected (ADA, 2009; Temme et al., 2013; USDA, USDHHS, 2010). Conversely, an ovo-lacto vegetarian diet is associated with a decreased prevalence of adiposity, hypertonia, stroke and type 2 diabetes (Craig, 2010) as well as a lower all-cause mortality (Orlich et al., 2013). By contrast, a purely vegan diet, which would be most beneficial in land use terms, could lead to an insufficient supply of essential nutrients, like vitamin B12, iron calcium, zinc, iodine (DGE, 2011; Dror & Allen, 2008; Millward & Garnett, 2010). Finally, nutritional studies have shown that an increased intake of stimulants (cocoa, coffee, tea, wine) is beneficial from a health perspective (Corti, Flammer, Hollenberg, & Luscher, 2009; Guilford & Pezzuto, 2011; Higdon & Frei, 2003, 2006). Considering this, it might be interesting for further studies to investigate, whether from a health perspective a meat-including diet with a restricted intake of stimulants is preferable or a vegetarian diet with an increased intake of stimulants. Generally, if diet shifts are pursued politically, then research should focus on broad and comprehensive health impact assessments to ensure that alterations in diets do not lead to disadvantageous side effects. Particular attention and further research should focus on potentially undernourished subgroups (such as toddlers, children, pregnant women, sick people, the elderly, etc.).

A reduction of avoidable food losses/wastage represents another way to balance the trade of virtual land. This approach applied to the recommendations of D-A-CH and UGB would allow, besides the ovo-lacto-vegetarian and vegan diet, also a positive balance of virtual land. Nevertheless, in case of the average diet (scenario 'intake 2006'), a reduction of avoidable food losses/wastage would not suffice to level out the virtual land balance.

Besides lower virtual land imports, described dietary changes would lead to significant domestic land savings, too. These areas could be used for (i) the intensified cultivation of energy crops, (ii) feed production for the increased export of meat and dairy products, (iii) a more extensive cultivation of food for direct human consumption, or (iv) forestry. They could also be (v) set aside for completely natural development. Choosing between these options is ultimately a political task. On the other hand, a diminished pressure on foreign countries by a balanced trade of virtual land with a decreased import dependency, not automatically leads to the disappearance of negative social and environmental repercussions in this countries. To address them necessitates effective policies – like land reforms but also nutrition and environmental policies – that are pro-poor, connecting community and household food-based strategies with fair distribution schemes of property rights and a regulated access to natural resources (Lipton, 2009; Wahlqvist et al., 2012).

Finally, to stabilize a reduced import dependency on the long term national and European initiatives dealing with the mitigation of soil sealing by settlement and industry expansion must be taken more thoroughly into account (EC, 2012). Prokop, Jobstmann, and Schönbauer (2011) analysed that in the EU detected land take between 1990 and 2006 was around 1000 $km^2\ a^{-1}$ (or 275 ha d^{-1}). In this period, the total settlement area increased by 9%, while the population increased by only 5% (the so called 'paradox of decoupled land take'). Land takes on agricultural soils are most relevant in Spain, France, Germany and Italy, varying from 20 to 50 ha d^{-1} (Gardi, Panagos, Bosco, & Brogniez, 2012). However, no quantitative goals exist on EU level nor in most member states. By contrast, in 2002 Germany committed to decrease the daily rate of built-up area and transport infrastructure expansion to 30 ha d^{-1} in 2020 (FG, 2002). In 2010, the last documented year, an area of 77 ha d^{-1} was affected by soil sealing. The corresponding progress report of the Federal Government (FG, 2012) states that "Continuing the average annual trend of the last few years would, however, still not be sufficient to reach the proposed reduction goal by 2020."

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.appet.2013.11.006.

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