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Analysis

Environmental impacts of changes to healthier diets in Europe☆

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ABSTRACT

Food consumption causes, together with mobility, shelter and the use of electrical products, most life cycle impacts of consumption. Meat and dairy are among the highest contributors to environmental impacts from food consumption. A healthier diet might have less environmental impacts. Using the E3IOT environmentally extended input output database developed in an EU study on Environmental Impacts of Products (EIPRO), this paper estimates the difference in impacts between the European status quo and three simulated diet baskets, i.e. a pattern according to universal dietary recommendations, the same pattern with reduced meat consumption, and a 'Mediterranean' pattern with reduced meat consumption. Production technologies, protein and energy intake were kept constant. Though this implies just moderate dietary shifts, impact reductions of up to 8% were possible in reduced meat scenarios. The slightly changed food costs do not lead to significant first order rebound effects. Second order rebounds were estimated by applying the CAPRI partial equilibrium model. This analysis showed that European meat production sector will most likely respond by higher exports to compensate for losses on the domestic meat market. Higher impact reductions probably would need more drastic diet changes.

1. Introduction, Goal and Scope

In June 2006 the European Council adopted its revised Sustainable Development Strategy (CEU, 2006). Key priorities formed the topic of Sustainable Consumption and Production (SCP) and the related environmental product policy (CEC, 2008). To support this policy, the Institute for Prospective Technical Studies of the European Commission (DG JRC IPTS) launched a comprehensive research program into the Environmental Impacts of Products ('EIPRO') and, subsequently, studies into the Improvement of Products ('IMPRO').

The EIPRO study showed that food (particularly meat and dairy), mobility and housing including energy using products cause over 70% of life cyele environmental impacts related to final household consumption expenditure in the EU (Tukker et al., 2006 and Tukker and Jansen, 2006). Typically, food drives 20–30% of the impacts of final household consumption. Meat and dairy have a dominant share (see e.g. studies part of EIPRO (Flynn et al., 2006; Huppes et al., 2006; Jansen and Thollier, 2006; Palm et al., 2006; Weidema et al., 2006), other authors (e.g. Biesiot and Noorman, 1999; Carlsson-Kanyama et al., 2005; Hendrickson et al., 2006; Hertwich, 2005; Jungbluth et al., 2000; Steinfeld et al., 2006) and a recent review published by the International Panel for the Sustainable Use of Natural Resources (Hertwich et al., 2010)). It is feared that both absolute and relative impacts of food consumption will rise due to population growth and wealth growth, the latter potentially leading to higher impact diets richer in meat and dairy (McMichael et al., 2007; Myers et al., 2004; Tilman, 1999).

A subsequent IMPRO study focused hence on the meat and dairy chain. It investigated optimizations related to e.g. feed production, feed digestion, food management by households (avoidance of food wastage), and power savings for e.g. cooling. Such socio-economically feasible improvement options would reduce impacts just by one fifth (Weidema et al., 2008). McMichael et al. (2007) come to similar estimates.

The scope of the IMPRO study excluded potential impact reductions by diet change. Various authors suggest this to be an important or even unavoidable impact reduction strategy (e.g. Baroni et al., 2006; Duchin, 2005; Goodland, 1995; McMichael et al., 2007; Reijnders and Soret, 2003; Stehfest et al., 2009). IPTS therefore

☆ The study report on which this paper is based contains a large amount of input data files, correspondence tables, and output data files for the various models used in the study. Due to space constraints such data is reproduced only in limited or aggregated form in this paper. We refer to Tukker et al. (2009) for further information. The full report inclusive all annexes can be downloaded from: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2359 (accessed 6 May 2010).

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commissioned a new study on diet changes (Tukker et al., 2009), of which the results are presented in this paper. Various scoping choices were made. The study should cover the 27 countries as part of the European Union in 2008. The study should take existing diets as a starting point. Directly intervening into consumer choices about diets of the EU population for environmental reasons alone was seen as an unrealistic policy proposition. Given problems like obesitas and the fast rising health costs in the EU, discussing the need for diet change from a health perspective was seen as much more viable. This implied that the study had to look for scenarios cutting out unhealthy diet habits (e.g. excess consumption of red meat) rather than to look for scenarios leading to environmental friendly diets (e.g. limiting meat and dairy intake to levels that just cover minimal needed animal protein intake; cf. Aiking et al., 2006; Aiking, 2011). The analysis should include indirect effects of diet changes, such as income effects (first order rebounds) and economy-wide reactions on change in demand for foodstuffs (second order rebounds) (Berkhout et al., 2000).

The next section first discusses the current and suggested alternative diets for Europe. The third section presents our approach for analyzing the environmental impacts of diet change including rebounds, in essence combining environmentally extended input output analysis with a partial general equilibrium model. The fourth section presents and discusses results where the fifth section ends with conclusions.

2. Current Diets in the EU27 and Alternative Diets with Positive Health Impacts

2.1. Data Sources

Various data sources are available that give insight in current food consumption in the EU. A first source of consumption data is a selection of data from national Food Consumption Surveys that are stored in aggregated form in the Concise European Food Consumption Database (CEFCD) by the European Food Safety Authority .[1] The foods in the database are aggregated into 15 food groups. This data is however only available for 15 EU countries. A second source is data on economic expenditure on food, for example data on household expenditure published by Eurostat (2010). These are however not detailed enough to discern individual meat and dairy categories. Another example is data on detailed Household Budget Surveys (HBS). While a detailed database for food via this route exists (DAFNE, Naska et al., 2007; Trichopoulou et al., 2005), such data is not available for all EU countries. A third source is the Food Balance Sheets (FBS), assembled by the Food and Agricultural Organization of the United Nations (FAO) from national statistics on production and imports and export of ingredients and primary agricultural foods. Such data are available for almost every country worldwide and are intended and mainly used for planning purposes, but also scientific analyses (e.g. de Boer et al., 2006). FBS estimates per country the amount of food *available* per capita per day and produces derived information, such as total energy, fat and protein availability per capita per day and for each commodity.[2]

The FBS data appeared to be most fit for our purpose. Data are consistent and available for all 27 EU countries to be covered.[3] Environmental impacts are not related to the food consumed (as in CEFCD), but related to the food made available (i.e. produced).[4] Unlike data expressed in economic terms, they include data on energy, fat and protein availability which facilitates developing scenarios of alternative, improved diets. Last but not least, the detailed classification of commodities at the level of primary agricultural products could be reasonably well translated into the corresponding categories used for calculation of environmental impact, but were also suited (after calibration) for translation of dietary recommendations. Section 3 will discuss how we linked the physical FBS data to the economic demand vector in the input–output model used for assessing environmental impacts.

For all EU member states, FBS covering 2003 was downloaded from the FAOSTAT website.[5] For each commodity (major and subcategories) the following variables were used: Food/capita/year (Kg), converted into Food/capita/day (g), Energy/capita/day (kcal), Proteins/capita/day (g) and Fat/capita/day (g). Also, the total daily per capita energy, fat and protein intake as well as the energy, fat and protein intake from vegetal and animal foods were extracted for each member state. The data set was enriched with data available from the FAO Yearbook on specific dairy products, i.e., teased out for whole milk, skimmed milk and cheese, as these were not available at the FAOSTAT website.[6] For each food item, its contribution of energy intake relative to total energy intake was calculated, as the comparison of current diets with dietary recommendations is based on the relative dietary composition. Furthermore, the ratio of energy derived from vegetal foods to energy derived from animal foods was calculated for each country. The population size of each country for 2003 was downloaded from the EUROSTAT website.[7]

2.2. Current Diets and Country Clusters

Due to the dietary diversity between EU27 countries it was not realistic to use one representative European diet as a basis for healthy diet scenarios. In order to come to a manageable number of representative diets, European countries were clustered into groups with similar diet patterns via two approaches, the analysis being conditioned to yield five clusters[8]:

1. Sorting by the ratio 'vegetal/animal energy' and apply a logical geographical cut-off. This ratio was a priori considered to be an important characteristic of (differences and similarities in) dietary patterns in Europe.
2. As a confirmative method, a formal cluster analysis (K-means), in which besides vegetal/animal energy also energy from the most important food groups at the aggregate level was included.

The ratio vegetal/animal energy appeared to be the decisive factor in the latter approach, so both approaches resulted in almost the same five clusters based on that factor. We shifted four countries to a neighboring cluster, based on a more logical geographical classification and only minor differences in the ratio vegetal/animal energy. For each cluster, aggregated food availability data were calculated as the mean of each food and nutrient, weighted by the population size of each country in that cluster. Furthermore, data available for each cluster were enriched with variables on saturated fat content, as reduction of saturated fat is an important dietary recommendation in Europe. Saturated fat for each food was based on the fat contributed by that food, multiplied by the ratio "saturated fat/total fat" calculated from data on total fat and saturated fat in the Dutch

[1] http://www.efsa.europa.eu/EFSA/ScientificPanels/DATEX/efsa_locale-1178620753812_ConciseEuropeanConsumptionDatabase.htm (last accessed 15 October 2008).

[2] http://faostat.fao.org/site/502/default.aspx (last accessed 15 October 2008).

[3] Only Luxemburg was not covered in the FBS. This is however the smallest country in the EU with just a few 100.000 inhabitants on a total of over 400 million in the EU27. Food consumption in Luxemburg was extrapolated using FBS data from Belgium, a neighboring country of which Luxemburg was part until the early 1800s.

[4] The difference is the amount of food bought and not consumed, or thrown away.

[5] http://faostat.fao.org/site/502/default.aspx (last accessed 15 October 2008).

[6] http://www.fao.org/statistics/yearbook/vol_1_1/site_en.asp?page=consumption (last accessed 15 October 2008).

[7] http://epp.eurostat.ec.europa.eu/portal/page?_pageid=0,1136184,0_45572595&_dad=portal&_schema=PORTAL (last accessed 15 October 2008).

[8] We refer to chapter 3 of the main report and chapter 3 in Annex 1 to Tukker et al. (2009).

Table 1
Diet composition of the five diet clusters in Europe based on *food availability* per capita in 2003, normalized on total daily energy availability. In bold: the highest contribution of each food group across the five clusters.

	Nordic plus France	Western European	South-Western European	Eastern European	South-East European
Dietary composition based on food availability	Finland France Denmark Sweden	Austria Hungary Ireland Belgium Slovenia Germany UK Netherlands	Cyprus Portugal Spain Malta	Lithuania Slovakia Poland Estonia Czech republic Latvia	Bulgaria Romania Greece Italy
Energy (kcal/day)	3537	3596	3483	3288	3590
Macronutrients	**energy%**	**energy%**	**energy%**	**energy%**	**energy%**
Energy from animal products	36.7	30.8	28.4	26.3	24.6
Total fat	40.3	36.3	39.4	30.1	34.6
Saturated fat	13.3	12.6	9.9	9.9	9.4
Protein	12.4	11.4	12.4	11.5	12.1
Commodities					
Cereals	24.6	25.2	22.9	33.7	**34.8**
Starchy roots	3.3	4.6	4.5	**6.4**	2.8
Sugar and Sweeteners	11.3	12.4	9.5	**13**	8.2
Pulses	0.5	0.6	**1.4**	0.6	1.2
Tree nuts	0.6	0.8	**1.3**	0.2	0.9
Oil crops	0.5	0.9	0.9	0.6	0.5
Vegetable oils	11.2	11.5	**17.9**	9.1	15.3
Vegetables	2.6	2	2.8	2	**3.2**
Fruits	2.7	3.6	**4**	2.1	3.9
Alcoholic beverages	4.8	**6.3**	5.6	5.4	4
Meat	**14.1**	11.2	13.5	10.3	9.9
Poultry	2.6	2.1	**2.9**	2.2	1.6
Red meat[2]	**11.5**	8.9	10.5	8.1	8
Bovine meat	2.4	1.5	1.7	0.9	**2.7**
Pig meat	**8.3**	6.9	7.8	7.2	4.7
Animal fats	2.7	**4.1**	2.1	3.3	2.1
Butter	**3.8**	2.7	0.6	2.5	1.1
Milk products (excl. butter)	11	**9.6**	7.7	6.7	8.8
Whole milk	3.2	4.8	**5.1**	2.3	4.3
Skim milk	**1.2**	1.1	0.5	0.8	0.6
Cheese	**6.6**	3.7	2	3.7	3.8
Eggs	**1.6**	1.4	1.4	1.4	1.2
Fish/seafood	1.5	0.9	**2.3**	1.1	0.9
Other[3]	**3.2**	2.2	1.6	1.6	1.2

[1]Representing food available for consumption rather than food consumed (see Section 2.1).
[2]Sum of bovine, mutton and goat, pig, and other meat.
[3]Food groups contributing very little to total energy intake (e.g. sugar crops, offal, stimulants).

food composition table.[9] This was not done for foods contributing negligible amounts of saturated fats, either because the food was hardly eaten or because it contained a very small amount of saturated fat. For main food groups including foods with varying saturated fat content, such as vegetable oils, the calculation was done at the subcategory level. For others, such as milk, the value was established at the main level.

Table 1 shows the classification of countries in clusters and diet compositions by cluster. The clusters Nordic countries + France (NC + F) and Western Europe (WE) are both characterized by a low ratio vegetal/animal energy, a high intake of animal fats and relatively low in cereals and vegetables consumption. However, NC + F consume more meat and fish than WE. South-East (SEE) and South-West (SWE) Europe are characterized by a relatively high consumption of vegetables and low consumption of animal fats. However, SEE consumes much more cereals (Italian pasta) and less meat, also resulting in much higher ratio vegetal/animal energy than SWE. SWE consumes much fish. The diet in Eastern Europe (EE) is characterized by a very high vegetal/animal energy ratio, low meat, high cereal consumption and relatively high fish consumption.

2.3. Dietary Scenarios with Positive Health Impacts

The next step was to identify diets with positive health impacts on the basis of generally accepted, authoritative recommendations. Such healthier dietary patterns contribute to the prevention of chronic diseases like obesity, type II diabetes (Brunner et al., 2008; Ramachandran and Snehalatha, 2004), cardiovascular diseases (Lloyd-Williams et al., 2008; WHO, 2002) and cancer (World Cancer Research Fund, American Institute for Cancer Research, 2007). A summary of the scientific evidence for (causal) relationships between dietary factors and obesity, type II diabetes mellitus, cardiovascular diseases, cancer, dental disorders and osteoporosis was drawn up after a joint WHO/FAO expert consultation. Part of this summary is provided in Table 2 (WHO/FAO, 2003).

Slightly different interpretations of the evidence, different dietary patterns to start from and differences in prevalence of chronic diseases may result in EU countries having slightly different population nutrition goals (EFSA, 2008; WHO/FAO, 2003). In general, however, there is an apparent consensus among (European) countries, especially on the population nutrition goals that should be in place to prevent chronic diseases (WHO/FAO, 2003). Such generally accepted recommendations include minimum levels of fruit, vegetable and

[9] See www.voedingswaardetabel.nl (last accessed 15 October 200). This was not done for foods contributing negligible amounts of saturated fats, either because the food was hardly eaten or because it contained a very small amount of saturated fat. For main food groups including foods with varying saturated fat content, such as vegetable oils, the calculation was done at the subgroup level. For others, such as milk, the value was established at the main level.

Table 2
Summary of the strength of the evidence for relationships between dietary factors and obesity, type II diabetes mellitus, cardiovascular diseases, cancer, dental disorders and osteoporosis (WHO/FAO, 2003).

High intake of	Obesity	Type II diabetes	CVD	Cancer	Dental disease	Osteoporosis
Energy and fats						
Energy dense foods	C↑					
Saturated fatty acids		P↑	C↑			
Trans fatty acids			C↑			
Dietary cholesterol			P↑			
Fish and fish oils			C↓			
Nuts (unsalted)			P↓			
Carbohydrate						
Dietary fiber	C↓	P↓	P↓			
Free sugars					C↑	
Starch					C-NR	
Whole-grain cereals			P↓			
Meat						
Preserved meat				P↑		
Fruits and vegetables						
Fruits and vegetables	C↓	P↓	C↓	P↓		
Whole fresh fruits					P-NR	
Alcoholic beverages						
High alcohol intake			C↑	C↑		C↑*
Low to moderate alcohol intake			C↓			

C↑: convincing evidence: increasing risk—C↓: convincing evidence: decreasing risk—C-NR: Convincing evidence for absence of relation—P↑: Probable relation: increasing risk—P↓: Probable relation: decreasing risk—P-NR: Probable lack of relation.
*In populations with a high fracture rate only; i.e., men and women aged 50–60 years and older.

fish intake and limits on saturated and trans fat intake. They are summarized in Table 3 (based on Health Council of the Netherlands, 2006; WHO/FAO, 2003; WHO Regional Office for Europe, 2003; World Cancer Research Fund and American Institute for Cancer Research, 2007).

Table 4 indicates as well which recommendations were simulated in two of the diet scenarios, by adapting the diets per country cluster presented before. Using existing diets as a starting point, they may therefore be regarded as not too drastic and most feasible alternatives for existing diets. Some recommendations were not simulated as they imply changes in processing that would not result in changes in environmental impact (i.e., reduction of trans fatty acids and increase of cereal fiber, which implies substitution of refined with whole grain) or since it would be impossible anyway to calculate effects on environmental impacts (fatty fish). For some country clusters, reducing energy intake from total fat to 30–35% (not a universal recommendation) would imply a very radical diet change; therefore, we only aimed at some reduction in those clusters. The first alternative scenario involved Europe-wide changes in the current food consumption patterns towards those specified by the population nutrition goals/nutrition guidelines. A second (more demanding) scenario included additionally a reduction of the intake of red meat and no consumption of processed meat. Energy intake and protein energy intake was kept by and large constant by rising where necessary intake of food items such as chicken meat, seafood and cereals.

Additionally, a third scenario was developed in which the diets in all country clusters were adapted on the basis of the prevailing diet in South-Western Europe and South- Eastern Europe. In essence this 'Mediterranean diet' is plant-centered; as compared to other diets in the northern parts of America and Europe it is composed of relatively frequent consumption of whole grains, fruit and vegetables, fish, olive oil, and alcohol combined with low to moderate intakes of dairy products, beef, pork, and lamb. Research has shown that the combined nutrients of the Mediterranean diet offer a significant source of disease prevention (see for example; Hardin-Fanning, 2008; James et al., 1989: Keys, 1995; Kushi et al., 1995A and B; Trichopoulou, 2001; Trichopoulou and Critselis, 2004; Trichopoulou and Vasilopoulou, 2000a, b). The simulated "Mediterranean" scenario largely agrees with the average of the SWE and SEE cluster pattern, but deviates substantially with respect to fish, poultry (2.3 and 2.8 energy percent respectively) and red meat (4.2 energy percent).

Recommendations for foods are formulated on the level of individual intake, whereas FBS represent per capita availability of foods. We calculated the factor required to make both data sources comparable by comparing the energy availability (FBS) with the energy intake of adults according to the Concise European Food

Table 3
Diet recommendations in relation to scenarios 1 and 2.

Food group or nutrient	Recommendation[1]	Recommendation used in	
		Scenario 1	Scenario 2
Vegetables	At least 200 g/day	Yes	Yes
Fruits	At least 200 g/day	Yes	Yes
Fish	At least 2x/week	Yes	Yes
Fatty fish	At least 1x/week	No	No
Red meat (beef, pork, lamb)[2]	Less than 300 g/week[3]	No	Yes
Processed meat[2]	No consumption	No	Yes
Fat[2]	Less than 30–35% of energy	No (Reduction)	No (reduction)
Saturated fat	Less than 10% of energy	Yes	Yes
Trans fatty acids	Less than 1% of energy	No	No
Sugar (added)[2]	Less than 10% of energy	Yes	Yes
Fiber	18–35 g/day	No	No
Salt	Less than 5–6 g/day	No	No

[1] For adults.
[2] Not a universal recommendation.
[3] Weight of meat as cooked.

Table 4
Summary of nutrient composition (energy%) of the average European diet (2003) and of simulated dietary scenarios.

Scenario	Type	Fat (en%)	Protein (en%)	Saturated fat (en%)
Status quo	2003	36.2	11.8	11.4
Scenario 1	Dietary recommendations	35.1	12.1	9.8
Scenario 2	Dietary recommendations + low red meat	33.6	11.7	8.9
Scenario 3	Mediterranean + reduced red meat	34.5	11.8	8.4

Consumption Database published by EFSA (EFSA, 2008). Altogether the factor varied between 1.7 and 2.1 between food groups and between countries, the difference being inedible parts of the foods (e.g., peels, bones) and waste of edible parts at the producer, retail and consumer level. We decided to use the factor 1.8 for all conversions of recommendations expressed as absolute amount of food, i.e. vegetables, fruits, fish and meat.

The simulation was performed for each cluster and each defined scenario using a spreadsheet. The principle was to change the share of food groups in the recommended direction, without changing the overall energy intake and ensuring a protein intake between 11 and 12 energy percent. To achieve this, substitutions were made with favorable foods, such as cereals (to compensate for energy and protein), pulses (to compensate for protein), tree nuts, and vegetable oils (to compensate, if necessary, for meat and animal fat). Substitutions were mostly made on the level of main food groups (e.g. cereals), unless there was a reason to do this on a subgroup level (e.g., types of meat and vegetable oils in scenario 3). For dairy products in scenarios 1 and 2, a shift was simulated towards a larger share of low-fat milk and cheese.

The results of the simulations for Europe (after aggregation of the results from the country clusters) and expressed as a percent change of each food group relative to the status quo (i.e. diet in 2003) are presented in Annex 1. The aggregated effect on nutrient composition of each scenario is given in Table 4.

3. Calculation of Impacts of Existing Diets and Three Alternative Scenarios

3.1. Introduction

Assessment of the environmental impacts of products or product groups typically is done in three steps: inventory of environmental interventions (such as emissions and primary resource use), impact assessment (usually by aggregating interventions to a limited number of indicators) and interpretation (cf. Guinée, 2002; ISO, 2006).[10] For the calculation of environmental interventions related to diets in Europe we made use of a technique known as environmentally extended input output analysis (EIOA, cf. Leontief and Ford, 1970: Miller and Blair, 1985; ten Raa, 2005, and EUROSTAT, 2008). For this particular study, the E3IOT EE IO model was used being currently the only comprehensive and detailed EE IO model available for Europe (see further Section 3.2). The interventions related to second order rebounds were simulated by linking E3IOT to what is probably the most authoritative European partial equilibrium model focused on the food sector, CAPRI (see further Section 3.3). Aggregation of interventions to impact indicators is discussed in Section 3.4.

3.2. Environmental Interventions of Diet Change Including First Order Rebounds: E3IOT

Environmental interventions (emissions and resource extraction) due to the production, consumption and waste disposal of food products are calculated with the E3IOT model (European Environmentally Extended Input Output Table).

E3IOT is an environmentally extended input–output model that in contrast to many other EIOA models includes environmental interventions during production, consumption and waste management phase of products. The E3IOT model represents the average EU economy for the year 2003 describing the economic inputs and outputs in monetary terms at a detailed level of 481 industry sectors, of which 284 deliver to final consumption by households. Allocated by industry sector, E3IOT includes about 1200 different environmental interventions, including fossil energy use, emissions to air, water and soil etc. Water use and land use occupations are however not covered in E3IOT. This arrangement of data allows calculating for each final demand category which fraction of the value was contributed by each industry sector, and with emissions and primary resource uses by sector known, this allows also calculating the life cycle emissions and resource use of this final demand category.

E3IOT is the updated version of the CEDA EU25 model which was used in the EIPRO study.[11] In this model, the environmental emissions for all food products have been estimated within the same consistent framework. An alternative would have been using data inventories from existing Life cycle assessments but this could have lead to inconsistencies in data sets and errors due to cut-offs (e.g. Lenzen, 2001). The E3IOT model not only allows for the assessment of the environmental interventions of food products only, but for all products purchased by final consumers. This makes it possible to place the environmental interventions of the food products in perspective with other (non-food) products and total economy wide environmental interventions or in terms of eco-efficiency.

We refer to previous publications where the details of E3IOT have been extensively described (e.g. Heijungs et al., 2006; Huppes et al., 2006; Tukker et al., 2006). The application of EIOA for product comparisons is often hampered by the very high level of aggregation in the product groups. E3IOT overcomes this challenge through its high level of product disaggregation, covering about 50 food product groups which are sufficient for our purpose. A shortcoming was that in various processes E3IOT does not differentiate between pig- and bovine meat, essential to model impacts of diet change. The relevant sectors were further detailed on the basis of LCA data available from the Danish food LCA database (Nielsen et al., 2003).[12]

The demarcation between environmental impacts associated with the final demand for food products and non-food products can be chosen in many ways. Environmental impacts associated with cooling, preparation (e.g. bakeries), transport etc. of food products by intermediate consumers have all been allocated to these food products. However in the use phase of products, environmental impacts associated with cooling, transport and preparation of food product in private households have been treated as separate categories and have not been allocated to food products. Data to be able to allocate such transport, cooling and heating activities of private households in a meaningful way to the household consumption of food products are not available. In essence, we hence have assumed that transport, cooling and preparation of food by final consumers have similar impacts in all diet scenarios. This probably is a reasonable assumption: fridges run continuously; there is no reason to assume that different diets lead to different amounts of food stored in fridges or different amounts of gas for cooking; petrol used for a shopping trip does hardly depend on the amount of food let alone the type of food bought, etc.

E3IOT could be used as follows to estimate the direct and first order rebound effects of diet changes (cf Annex 1).

1. A correspondence table was constructed between the E3IOT food categories and the FBS food categories used in the analysis of diets (Annex 1).[13]

[10] In a full Life cycle assessment is preceded by a goal and scope step, in this paper briefly discussed in Section 2.

[11] CEDA EU25 was itself an expansion of the CEDA model built by Sangwon Suh (2004a) for the US. The elaboration of CEDA EU25 into E3IOT mainly concerned the development of more user-friendly interfaces, among others by linking the original CEDA EU25 database directly with the CMLCA software for Life cycle impact assessment. CMLCA has been developed in house by CML. The mathematical basis for the calculations has been described in Heijungs and Suh (2002) and Heijungs et al. (2006).

[12] See for a more detailed description chapter 5.2 in Tukker et al. (2009).

[13] See: table 3 in Tukker et al., 2009, downoadable as per note 1.

2. The status quo 2003 dietary pattern based on FBS, with the foods expressed as percent contribution to total energy availability, was assumed to correspond to the status quo of final demand for food products in monetary terms as recorded in the input–output table for the EU25 in 2003 in E3IOT.
3. For each scenario, the diet changes expressed as percentage change relative to the status quo in the FBS as described above hence can be expressed with the same relative changes relative to the (monetary) status quo in the E3IOT model.[14]
4. This leads to four different final demand vectors for food, related to the status quo ('scenario 0') and the three other scenarios ('scenario 1, 2, 3').

The environmental impacts of diet change without taking into account first and second order rebound effects, now simply can be calculated by running E3IOT with the 4 different final demand vectors for food, keeping all non-food expenditures constant (called 'scenario x − All').

It appeared however that the costs of the alternative food baskets differed slightly from the status quo. To estimate this so-called 'income effect' (or first-order rebound), we also ran scenarios in which the expenditure on all non-food products was proportionally adjusted so that the same final consumption expenditure would be at stake as in the status quo (called 'scenario x − All + first order).[15]

3.3. Environmental Interventions of Diet Change Including Second Order Rebounds: Linking CAPRI to E3IOT

The changed demand for food products in the three diet change scenarios can result in price changes that in turn may result in structural changes in the primary agricultural sectors, as well as changes in import and export volumes. The E3IOT model is an input–output model with fixed technical coefficients and cannot address such dynamic aspects of the economy. The study therefore used additionally a partial equilibrium model, called CAPRI, to integrate the impacts of price changes, substitution effects in agricultural production and interactions between the European and world-wide agricultural markets in the analysis of dietary scenarios. CAPRI stands for Common Agricultural Policy Regionalised Impact and is an economic model focusing on the agricultural sector.[16] It makes use of non linear mathematical programming tools to maximize regional agricultural income in the EU27 with explicit consideration of policy instruments of support (i.e. Common Agricultural Policy) within an open economy, so that price interactions with other regions of the world are taken into account. CAPRI consists of a supply and a market module. For a detailed description of CAPRI we refer to Britz et al. (2008).

The approach used in essence was the following. In order to link the agricultural sectors in CAPRI with the E3IOT model, a correspondence table was built linking the food related E3IOT final demand categories, with the more disaggregated CAPRI food sectors. For each scenario, domestic human food consumption resulted in a changed supply vector in E3IOT, which in turn was transferred into CAPRI as relative demand change. As a result, a new market equilibrium is achieved in CAPRI, yielding new domestic supply and import quantities valued at the equilibrium prices. The new resulting domestic supply plus import values in CAPRI are then summed over and transferred back to E3IOT as a new vector of total supply, which is then used to calculate changed environmental impacts.

This approach gives an approximate insight into the 2nd order economic and environmental effects of diet changes. Limitations of this approach are for instance that any price changes are not reflected by E3IOT, whereas in the new market equilibrium the same economic demand may not correspond with the same physical demand (which after all drives environmental impacts). Furthermore, further rippling of structural changes in the primary agricultural sectors to food processing sectors and other industry sectors is not accounted for.

Table 5
Weights for aggregate environmental score (percentages).

Impact category	Weights (%)	Reference for method of impact assessment for the impact category
Abiotic resource depletion	5	Guinée, 2002
Climate change	35	IPCC, 2007
Ozone depletion	5	WMO, 1992 & 1995 & 1999
Human toxicity	17	Huijbregts, 1999a, 2000 & Huijbregts et al., 2000
Ecotoxicity	7	Huijbregts, 1999a, 2000 & Huijbregts et al., 2000
Photochemical oxidant formation	9	Jenkin and Hayman, 1999; Derwent et al., 1998
Terrestrial acidification	7	Huijbregts, 1999b
Freshwater eutrophication	15	Heijungs et al., 1992

3.4. Aggregation of Environmental Interventions to Indicators

The initial result of the E3IOT calculations are the life cycle environmental interventions related to a final demand vector, i.e. emissions and primary resource use. For the interpretation of these outcomes, the impact analysis step has been added as it is common in the environmental life cycle assessment of products. This step encompasses the translation of the environmental interventions from the inventory result into contributions to relevant impact categories, such as abiotic resource use and global warming.

This so called impact assessment (IA) step has been based on the CML2002 IA methodology. At the time of doing this research, this was one of the most authoritative LCA manuals. More recent methods such as ReCiPe (Goedkoop et al., 2009) or the IA method from the European Platform on LCA were not yet available. It considers the following impact categories (Guinée, 2002)[17]:

- Climate change
- Ozone depletion
- Terrestrial acidification
- Freshwater eutrophication
- Human toxicity
- Photochemical oxidant formation
- Ecotoxicity
- Abiotic resource depletion

The resulting scores on impact categories are presented in normalized and weighted form. In the normalization step the scores for each impact category for a specific product are expressed as share of the total European score on that impact category (Oers L van et al., 2001). The total European score on an impact category is calculated from the total emission inventory for the EU in 2003 which is

[14] There is one point that may be criticized here. The FBS gives food availability (or purchases) per capita, and not food intake — the difference being losses of food residues. The alternative scenarios have been determined in such a way that the same *availability* of nutritional value (particularly with regard to energy) is ensured. It may be that losses of certain food items are higher or lower as of other food items, and in that case a somewhat different *actual intake* may be at stake between our scenarios. Due to lack of insight in food loss per food item per country cluster, we had no way to correct for this if relevant.

[15] This proportional distribution is a relatively simple approach. In the ideal situation one would have had insight in price elasticities for all final consumption categories in E3IOT — but such data for the EU27 is not available. Compare Lenzen and Dey (2002) and Girod and de Haan (2010) for attempts in analyzing how such rebounds depend on e.g. income of households.

[16] See: www.capri-model.org, accessed 9 August 2010.

[17] Note that biotic resource depletion, relevant for among other fish consumption, is outside the scope of inventory in the E3IOT model, and hence cannot be included in the impact assessment step.

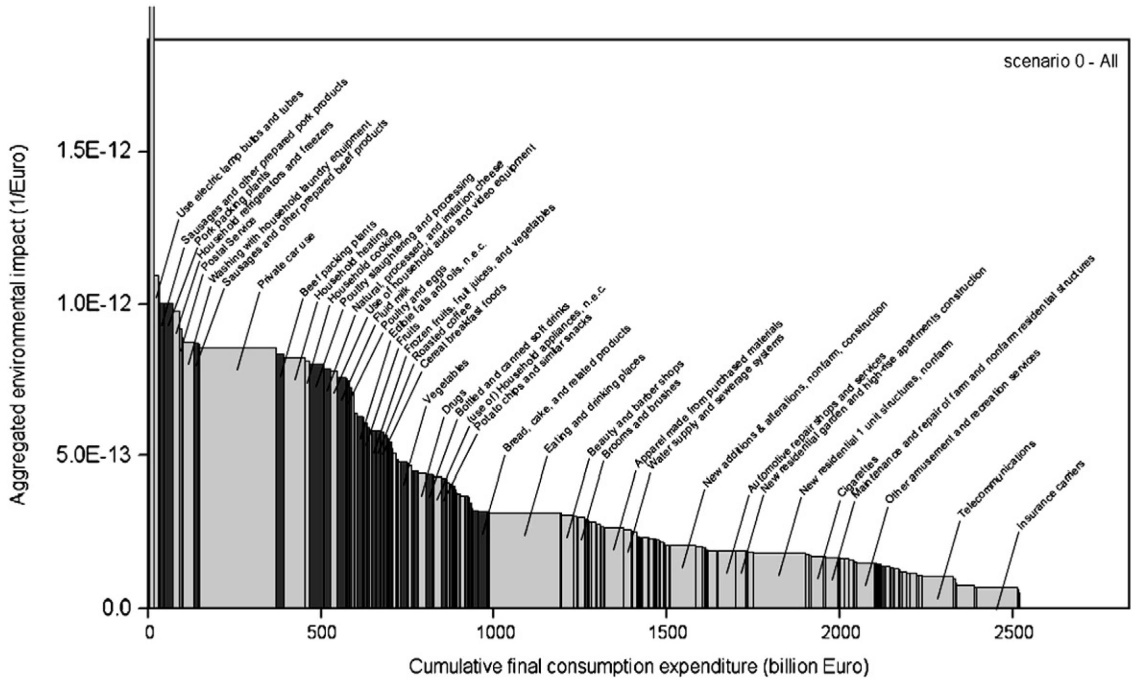

Fig. 1. Environmental impact of final consumption, in descending order of impact per Euro for 'scenario 0 — All'. The first column from the left which has been topped consists of the household use of three products i.e. nonwoven fabrics 5.45×10^{-12}, miscellaneous crops 4.47×10^{-12} and the household use of pesticides and agricultural chemicals 2.58×10^{-12}.

equivalent to the total emissions resulting from EU final demand. Thus, for each product, eight normalized scores result, one for each impact category.

For visualization purposes it was further desirable to aggregate the scores per impact category into an overall, single score. There is no authoritative methodology for this weighting yet. We chose to use the weights as used in Dutch environmental policy for the oil and gas producing industry (NOGEPA) (Huppes et al., 2007; see Table 5). Given that the choice for a certain IA method and weighting scheme is somewhat arbitrary, the report underlying this paper applied as well the Eco-indicator 99 method (Goedkoop and Spriensma, 1999), which forms an alternative for the IA and weighting methods shown here. This alternative approach did not lead to differences in quantitative results nor conclusions.

4. Results and Discussion

4.1. Overview of Results and Discussion of the Status quo

Fig. 1 shows for the Status quo (scenario 0) aggregated, weighted impacts per Euro on the y axis and the expenditure on products on the x axis, the surface being total impacts of European final consumption.[18] Products that contribute more than 0.5% to total aggregated environmental impacts in the European Union are labeled. Tables 6 to 8 reflect expenditures, global warming impacts, and aggregated environmental impacts for all scenarios including variations with first and second order rebound effects. A full numerical overview of the aggregated environmental impacts associated with the household use of products inclusive the food products for the Status quo scenario can be found in Chapter 9 of Annex 1 of Tukker et al. (2009). Figs. 2 to 4 specify for all scenarios the change in impacts compared to the status quo, split up by impact category. These results are discussed in the next sections.

We find that in the Status quo aggregated life cycle impacts of food are 27% of those of total consumption. Meat and dairy contribute over half to this, and appear to have relatively high impacts per Euro.[19] The picture for global warming is similar. The Global warming figures we find are slightly less than the 18% global average contribution of meat and dairy mentioned in the UN/FAO study 'Livestock's Long Shadow' (Steinfeld et al., 2006). Europe's Global warming contribution due to fossil energy use is higher than the global average, so that it is logical to expect a lower relative contribution of meat and dairy.[20] Overall our findings for the Status quo are in line with existing literature (compare Nijdam et al., 2005; Weidema et al., 2006).

4.2. Direct Impacts of Diet Change

The first three rows labeled with sub-scenario 'All' in Table 9 provide the result of the direct change in impacts due to the three diet change scenarios. A change from the baseline scenario to the alternative diets 1, 2 and 3 results in the following outcomes:

- Scenario 1 provides no reduction in environmental impacts. The positive effect of limited reductions in meat intake appears to be canceled out by enhanced intake of fish, cereals, and vegetables.
- In scenario 2 and 3 result the environmental impacts related to food consumption decrease from 27% to 25% out of all impacts related to final consumption in EU27. This 2% reduction corresponds to a reduction of the impacts related to food consumption of around 8%. This reduction is mainly caused by replacing red meat for about 40% by chicken, seafood and cereals. We did not change the total milk and cheese consumption which is suggested

[18] This essentially is the same figure as presented in the original EIPRO study (Huppes et al., 2006), but now including the refinements made in E3IOT afterwards such as detailing pig and bovine meat.

[19] We defined meat and dairy products as products fully or predominantly consisting of meat and dairy, delivered to final consumers. We did not take into account meat and (particularly) dairy products included in other products for final consumption, such as eggs or milk used in bread.

[20] Another factor may be that our Global warming figures do not include land use change. This is true for both the impacts of meat and dairy products as well as the reference value (Global warming due to total European final consumption), so to some extent this factor cancels out in the relative comparison.

Table 6
Expenditure on food and non food in the EU27 in the different scenarios (billion Euro).

	Non food	Food	Total
Scenario 0 — All	2069	447	2516
Scenario 1 — All	2069	455	2524
Scenario 2 — All	2069	433	2502
Scenario 3 — All	2069	444	2513
Scenario 1 — All + first order	2061	455	2516
Scenario 2 — All + first order	2083	433	2516
Scenario 3 — All + first order	2072	444	2516

by Weidema et al. (2008) to count for almost half of the impacts of meat and dairy.[21]

- Various other diet changes like limiting salt intake or limiting trans fatty acid intake are not likely to have high environmental implications, since it concerns small mass flows (salt), or technical changes in the production chain that do not lead to major changes in primary food production (e.g. prevention of development of trans fatty acids in fat processing).

Tables 7 and 8 show that the results for Global warming are similar, but Fig. 2 shows that for other impact categories, more significant changes are at stake. Acidification and euthrophication are around 4 to 7% lower in scenarios 2 and 3, mainly due to lower manure production and related NH3 emissions from livestock. Ecotoxicity is slightly up, however, probably due to slightly higher pesticide emissions related to higher consumption of vegetable food.

It has to be noted that E3IOT is not capable of assessing the impacts on biotic depletion. Negative impacts of enhanced fish consumption in scenario 3 are hence not fully taken into account.

4.3. Impacts of Diet Change Including First Order Effects

As shown by Table 9, the food basket in scenarios 1, 2 and 3 have slightly different costs compared to the food basket in the baseline scenario 0. As indicated, we estimated that consumers had to buy less food products in the diet scenarios than in the status quo scenario. As approximation of first order rebounds this extra purchasing power was redistributed proportionally over the non-food products so that the original total household budget would be spent.

By definition, the scenario 0, being the status quo, has no first order effects. For the other scenarios, Tables 7 to 9 show that for the both global warming as aggregated impacts the first order rebound is limited. Results are very similar to those presented in Section 4.2. Only in scenario 2 it appears that the environmental impacts do not only decrease due to changes in dietary habits, but at the same time slightly increase due to changed consumption of non-food goods. The net result is in this scenario 2 is a somewhat lower than 2% reduction of overall environmental impacts related to final consumption in EU.

In summary the environmental impacts of diet change with and without first order effects are almost the same. This is also true when we look at the individual impact categories (see Fig. 3).

4.4. Impacts of Diet Change Including Second Order Effects

The CAPRI calculations show that in response to a changed final consumption of food products, agricultural production switches to increased exports and reduced imports of red meat products. At the same time, production and imports of products with higher demand, such as fish, increased.

The overall implication is that the reduction of environmental impacts in scenarios 1, 2, and 3 becomes even less limited (see Tables 7 to 9).

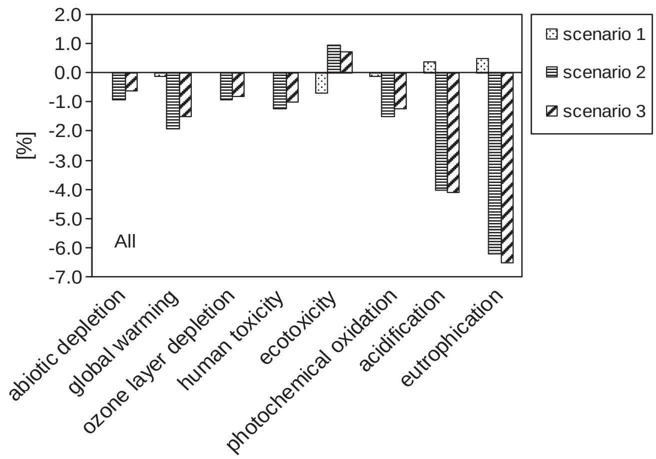

Fig. 2. Relative changes per scenario per impact category, compared to the total environmental impact in Europe in the status quo (scenario 0 — All).

scenarios 2 and 3 give reductions of around 0.6% of all environmental impacts related to European final consumption (or about 2% on the 27% of the share of impacts of food on the total impacts of European final consumption). Fig. 4 shows that particularly the reductions on climate change, acidification and eutrophication become less pronounced. The slight increase of ecotoxicity in the different scenarios is similar to the calculations without CAPRI in Figs. 2 and 3.

The 2nd order calculation in essence assesses the impacts of changes in final consumption in Europe plus changes in exports. The rising exports of red meat explain why impacts in Europe diminish not that fast since production is not reduced according to reduction in domestic final demand. It may be that the difference that is exported avoids production and related impacts abroad, an issue not taken into account.

5. Conclusions

This study has analyzed the impacts of final consumption of food in the EU, in relation to three scenarios for moderate changes towards healthier diets. The E3IOT model suggests that 27% of the impacts of European total consumption are related to food consumption. This is in line with results of other work (e.g. Flynn et al., 2006; Hertwich, 2005; Nijdam et al., 2005; Weidema et al., 2006). This paper confirms further the relative importance of meat and dairy consumption as drivers of impacts of food consumption (e.g. Steinfeld et al., 2006).[22]

Changes to healthier diets without significant meat and dairy intake reductions would result in rather minor reductions of environmental impacts in Europe.[23] Dietary recommendation

[21] From a nutritional point of view, milk consumption can not be reduced to a large extent, unless profound compensation by foods providing high quality protein and specific minerals and vitamins are made available.

[22] Pitesky et al. (2009) wrote a comment on this FAO study ‘Livestock's Long Shadow (LLS)’ (Steinfeld et al., 2006), that in the media was perceived as fundamental critique. LLS suggests that 18% of anthropogenic global warming caused by livestock production over its life cycle, well in line with our results and others we refer to. Pitesky rightly points out that this 18% concerns direct and indirect (life cycle) impacts, e.g. including land use change for feed production. This should not be compared to direct emissions of car transport (as apparently was done in LLS) — direct emissions from livestock obviously are lower than those of car transport. The large number of life-cycle based studies quoted by us, however, show unambiguously that when looking at meat and dairy as well as transport from a final consumption perspective, both are among the consumption categories most relevant for global warming.

[23] It is difficult to assess if this finding can be transferred to other regions in the World. In some regions the rising demand for meat and dairy could lead to land use change which can contribute significantly to global warming. A similar study – particularly if it would include land use – for such a region could have shown more significant impact reductions related to diet change.

Table 7
Global warming impacts (excluding land use change) by final consumption of food- and non food product groups in the EU around 2000 for scenario 0, 1, 2 and 3, and the same scenarios including 1st and 2nd order effects. Totals may not sum up due to rounding off errors.

	Global warming impacts (in % relative to total life cycle impacts of final EU consumption in status quo = 100%)			
	Scenario 0: Status quo	Scenario 1 : Recommendations	Scenario 2: Recommendations including red meat reduction	Scenario 3: Mediterranean
Sub-scenario: all				
Meat and dairy	13.6	13.0	10.6	10.3
Other food	11.8	12.7	12.9	13.7
Total food	25.4	25.7	23.5	23.9
Non-food	74.6	74.6	74.6	74.6
Total	100.0	100.3	98.1	98.5
Sub-scenario: All + first order				
Meat and dairy	n.r	13.0	10.6	10.3
Other food	n.r	12.7	12.9	13.7
Total food	n.r	25.7	23.5	23.9
Non-food	n.r	74.2	75.0	74.6
Total	n.r	99.9	98.5	98.5
Subscenario: All + first and 2nd order	n.r	100.0	99.4	99.4

Table 8
Global warming impacts (excluding land use change) per capita by final consumption of food- and non food product groups in the EU around 2000 for scenarios 0, 1, 2 and 3, and the same scenarios including 1st and 2nd order effects.

	Global warming impacts (in $kgCO_2$ eq per capita)			
	Scenario 0: status quo	Scenario 1 : recommendations	Scenario 2: recommendations including red meat reduction	Scenario 3: mediterranean
Sub-scenario: all				
Meat and dairy	1.39E + 03	1.33E + 03	1.08E + 03	1.05E + 03
Other food	1.21E + 03	1.29E + 03	1.32E + 03	1.39E + 03
Total food	2.59E + 03	2.63E + 03	2.40E + 03	2.44E + 03
Non-food	7.62E + 03	7.62E + 03	7.62E + 03	7.62E + 03
Total	1.02E + 04	1.02E + 04	1.00E + 04	1.01E + 04
Sub-scenario: All + first order				
Meat and dairy	*n.r*	1.33E + 03	1.08E + 03	1.05E + 03
Other food	*n.r*	1.29E + 03	1.32E + 03	1.39E + 03
Total food	n.r	2.63E + 03	2.40E + 03	2.44E + 03
Non-food	n.r	7.58E + 03	7.66E + 03	7.62E + 03
Total	n.r	1.02E + 04	1.00E + 04	1.01E + 04
Subscenario: All + first and 2nd order	n.r	1.02E + 04	1.01E + 04	1.01E + 04

Per capita data calculated using an EU27 population of 482,767,710 people in 2000 (personal communication with Stephan Moll, Eurostat).

Table 9
Aggregated environmental impacts of final consumption of food- and non food product groups in the EU for scenarios 0, 1, 2 and 3, and the same scenarios including 1st and 2nd order effects. Totals may not sum up due to rounding off errors.

	Aggregated environmental impacts (in % relative to total life cycle impacts of final EU consumption in status quo = 100%)			
	Scenario 0: status quo	Scenario 1 : recommendations	Scenario 2: recommendations including red meat reduction	Scenario 3: mediterranean
Sub-scenario: All				
Meat and dairy	15.0	14.5	11.8	11.5
Other food	11.7	12.4	12.7	13.2
Total food	26.7	26.8	24.5	24.7
Non-food	73.3	73.2	73.2	73.2
Total	100.0	100.1	97.8	97.9
Sub-scenario: All + first order				
Meat and dairy	n.r	14.5	11.8	11.5
Other food	n.r	12.4	12.7	13.2
Total food	n.r	26.8	24.5	24.7
Non-food	n.r	72.9	73.7	73.3
Total	n.r	99.8	98.2	97.9
Subscenario: All + first and 2nd order	n.r	99.8	99.5	99.3

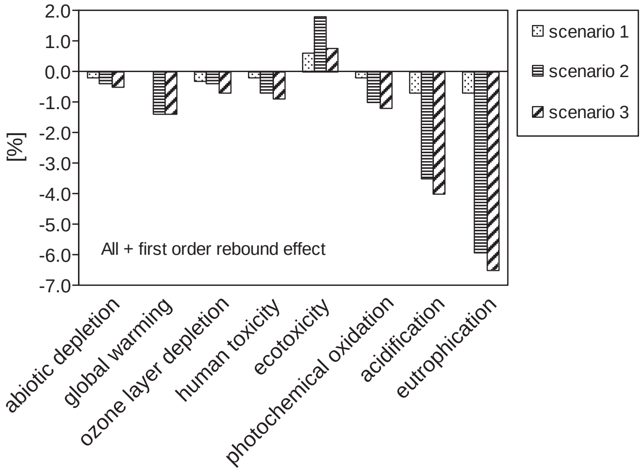

Fig. 3. Relative changes per scenario per impact category including first order rebounds. Reference is the total environmental impact in Europe in the status quo (scenario 0 — All).

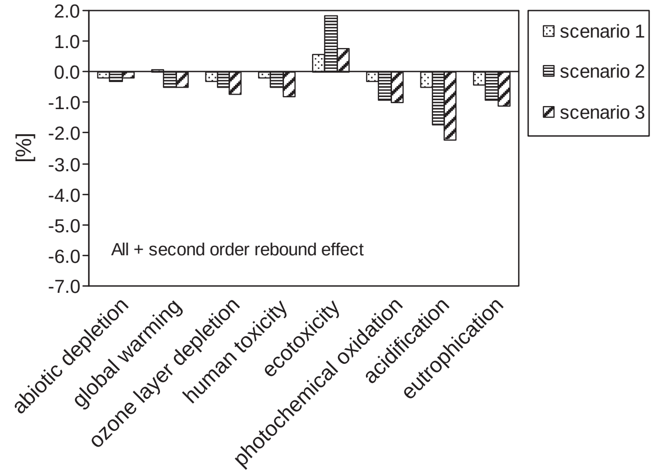

Fig. 4. Relative changes per scenario per impact category including second order rebounds. Reference is the total environmental impact in Europe in the status quo (scenario 0 — All).

scenarios that reduce significantly the intake of red meat and replace it with chicken, fish and cereals (scenario 2 and scenario 3, the so-called Mediterranean diet) can lead to a reduction of impacts of food consumption by about 8%, or about 2% of the impacts of final consumption in Europe of all goods. This conclusion also holds when first order rebounds (or income effects) are taken into account. Modeling of secondary rebounds (changes of production structures) with the CAPRI model suggests however that European production of food items like beef will not drop in line with domestic final consumption. The European meat production sector will most likely respond by higher exports to compensate for losses on the domestic meat market. This hence implies that impacts in Europe will drop even less.[24]

The shift to alternative diets may be recommendable however for the following reasons:

- An 8% reduction of impacts by the moderate diet changes involved are not without significance.
- The E3IOT model does not include agricultural land use, which is likely to be reduced significantly in scenarios 2 and 3. Stehfest et al. (2009) suggest that a main benefit of low meat diets is alternative land use that can contribute highly to mitigating climate change (e.g. by biofuel production or growth of natural vegetation that forms an additional carbon sink).[25]
- The CAPRI calculations show lower impact reductions in Europe when second order rebounds are included, but this is due to increase of exports of red meat, which might imply reduced environmental pressure in countries exported to.
- The alternative diets in this study have been developed from the perspective of healthier nutrition. The benefits of a large scale reduction of obesity; diabetes, cardiovascular diseases or even cancer are sufficient justification in itself.

Overall our study suggests that moderate diet changes are not enough to reduce impacts from food consumption drastically. Weidema et al. (2008) and McMichael et al. (2007) suggest further that the scope of impact reductions by technical means is limited to about 20%. This improvement potential includes reductions of impacts by reasonable limitations of food losses along the food chain, for instance at the consumer side (Weidema et al., 2008).[26] Various authors hence suggest that sustainability and reaching 'Factor X' targets require more drastic diet changes as we considered. As a first option one could consider reducing overall food intake: in several developed societies nutritional energy intake is higher as recommended (e.g. Lenzen and Dey, 2002). However, quantifying the potential environmental benefits needs careful analysis of various factors. which goes beyond the scope of this paper. Obesitas is caused by relatively small excess intakes and intake reduction could hence have limited environmental benefits. Furthermore, increasing physical activity (which in turn increases energy requirement) is an even more important recommendation to enhance health. At the same time, some authors claim that overweight leads to an increase in body energy demand and hence higher food consumption (Cardella et al., 2009). A second option, focusing on a more drastic reduction of consumption of the most impact intensive food items hence may work better. According to Baroni et al. carefully crafted omnivorous, vegetarian and vegan diets may reduce impacts compared to a regular (Italian) diet by over 50%. McMichael et al. (2007) propose a global maximum average meat consumption of 90 g per day to combat climate change. Not more than 50 g per day should come from red meat from ruminants (ie, cattle, sheep, goats, and other digastric grazers). The proposal of McMichael and colleagues implies a reduction of meat consumption by factors 1.5 to 2 in most European countries. With food however causing such a dominant part of impacts of total consumption, and the need to reduce e.g. greenhouse gas emissions with 50 to 80% by 2050 (IPCC, 2007; Stern, 2006), further debate about reduced meat and dairy consumption seems inevitable unless technical improvement options giving higher impact reductions are found. With some authors suggesting that dairy products cause as much impacts as meat (Weidema et al., 2008), it may further be needed to expand the discussion beyond the issue of reduced meat consumption only.

[24] It implies changes due to (policies stimulating)_diet change alone. It is of course possible that other policies can reduce impacts further, but these were not studied in this analysis.

[25] Stehfest et al. (2009) used an integrated assessment model in their calculations, and from that perspective it probably makes sense to include scenarios that take alternative land use into account. One can also argue that the decision to use the additional available land for e.g. biofuel production is a policy decision that needs dedicated policy action. We chose a scope in which we mainly focused in the autonomous consequences of diet change, without additional policies, and hence for us it was less logical to include the type of scenarios Stehfest et al. used.

[26] One must be careful in drawing less appropriate conclusions, though. As indicated in Section 2.3 there is a significant difference between the amount of food purchased and food consumed, but this difference includes inedible parts such as bones and peels.

Appendix A Annex 1

Changes in food use relative to status quo (%) in the three dietary scenarios aggregated over five regional clusters presented in Table 1 and linked to E3IOT items.

E3IOT category	E3IOT code	Items SHEETS FOOD BALANCE	Relative change (%)		
			Scenario 1	Scenario 2	Scenario 3
Bread, cake, and related products	[I78]	Cereals	5.2	10.6	14.6
Cereal breakfast foods	[I72]	Cereals	5.2	10.6	14.6
Cookies and crackers	[I79]	Cereals	0.0	0.0	14.6
Flour and other grain mill products	[I71]	Cereals	5.2	10.6	14.6
Frozen bakery products, except bread	[I80]	Cereals	5.2	10.6	14.6
Macaroni, spaghetti, vermicelli, and noodles	[I98]	Cereals	5.2	10.6	14.6
Potato chips and similar snacks	[I99]	Starchy roots			−4.3
Prepared flour mixes and doughs	[I73]	Cereals	5.2	10.6	14.6
Beef packing plants	[I53]	Beef	−9.1	−40.3	−58.8
Pork packing plants	[I55]	Pork	−7.2	−39.2	−58.8
Miscellaneous livestock	[I5]	Mutton&Goat/Other meat		−58.0	−58.8
Poultry slaughtering and processing	[I57]	Poultry		24.0	28.9
Sausages and other prepared beef products	[I54]	Beef	−9.1	−100	−58.8
Sausages and other prepared pork products	[I56]	Pork	−7.2	−100	−58.8
Canned and cured fish and seafoods	[I63]	Fish and seafood	18.9	18.9	95.4
Commercial fishing	[I19]	Fish and seafood	18.9	18.9	95.4
Prepared fresh or frozen fish and seafoods	[I68]	Fish and seafood	18.9	18.9	95.4
Creamery butter	[I58]	Butter	−41.9	−41.9	−47.6
Dairy farm products	[I1]	Whole Milk/Skimmed milk			−9.3
Dry, condensed, and evaporated dairy products	[I60]	Whole Milk/Skimmed milk			−9.3
Fluid milk	[I62]	Whole Milk/Skimmed milk			−9.3
Natural, processed, and imitation cheese	[I59]	Cheese			−9.3
Poultry and eggs	[I2]	Eggs			−6.0
Edible fats and oils, n.e.c.	[I96]	Vegetable oils	18.3	20.2	40.6
Oil bearing crops	[I16]	Oilcrops			33.1
Dehydrated fruits, vegetables, and soups	[I66]	Fruits	25.8	25.8	18.6
Frozen fruits, fruit juices, and vegetables	[I69]	Fruits/Vegetables	22.1	22.1	18.6
Fruits	[I11]	Fruits	25.8	25.8	18.6
Tree nuts	[I12]	Treenuts		151.5	62.2
Greenhouse and nursery products	[I17]	Vegetables	17.4	17.4	22.0
Vegetables	[I13]	Vegetables	17.4	17.4	22.0
Candy and other confectionery products	[I84]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Canned fruits, vegetables, preserves, jams, and jellies	[I65]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Chocolate and cocoa products	[I82]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Ice cream and frozen desserts	[I61]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Sugar	[I81]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Canned specialties	[I64]				
Food preparations, n.e.c.	[I100]				
Frozen specialties, n.e.c.	[I70]				
Manufactured ice	[I97]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Miscellaneous crops	[I15]	Starchy roots/Pulses		5.1	−1.4
Pickles, sauces, and salad dressings	[I67]				
Salted and roasted nuts and seeds	[I83]	Treenuts/Oilcrops		119.0	55.0
Roasted coffee	[I95]				
Bottled and canned soft drinks	[I89]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Flavoring extracts and flavoring syrups, n.e.c.	[I90]	Sugar and Sweeteners	−13.7	−13.7	−23.3
Distilled and blended liquors	[I88]	Alcoholic beverages			−7.9
Wines, brandy, and brandy spirits	[I87]	Alcoholic beverages			−7.9
Malt beverages	[I85]	Alcoholic beverages			−7.9

Note: an empty cell implies that there was no change in purchase assumed of the E3IOT category.

References

Aiking, H., 2011. Future protein supply. Trends Food Sci. Technol. 22, 112–120.

Aiking, H., de Boer, J., Vereijken, J., 2006. Sustainable protein consumption. pigs or peas? Environment and Policy series. Springer, Dordrecht, Netherlands.

Baroni, L, L Cenci, M Tettamanti and M Berati (2006). Evaluating the environmental impact of various dietary patterns combined with different food production systems. European Journal of Clinical Nutrition 2007 Feb;61(2):279–86.

Berkhout, P.H.G., Muskens, J.C., Velthuijsen, J.W., 2000. Defining the rebound effect. Energy Policy 28 (6–7), 425–432.

Biesiot, W., Noorman, K.J., 1999. Energy requirements of household consumption: a case study of The Netherlands. Ecol. Econ. 28 (3), 367–383.

Britz, W., Pérez, Domínguez I., Heckelei, T., 2008. A comparison of CAPRI and SEAMLESS-IF as Integrated Modelling Systems. In: Brouwer, F., van Ittersum, M.K. (Eds.), Environmental and Agricultural Modelling: Integrated Approaches for Policy Impact Assessment. Springer.

Brunner, E.J., Mosdøl, A., Witte, D.R., Martikainen, P., Stafford, M., Shipley, A.J., Marmot, M.G., 2008. Dietary patterns and 15-y risks of major coronary events, diabetes, and mortality. Am. J. Clin. Nutr. 87 (5), 1414–1421.

Cardella, M., Tugnoli, A., Santarelli, F., 2009. An LCA approach to the Environmental Impact of Overweight and Obesity. Program book, 15th LCA Case Study Symposium, 22–23 January 2009, Paris France. SETAC Europe, Brussels, Belgium.

Carlsson-Kanyama, A., Engström, R., Kok, R., 2005. Indirect and direct energy requirements of city households in Sweden - options for reduction, lessons from modeling. J. Ind. Ecol. 9 (1–2), 221–235.

Commission of the European Communities, 2008. Communication from the commission to the European parliament. The Council, The European Economic And SocialCommittee And The Committee Of The Regions on the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan. COM (2008) 397 final. CEC, Brussels, Belgium.

Council of the European Union, 2006. Renewed EU Sustainable Development Strategy. 10917/06, Brussels, Belgium, 26 June 2006.

de Boer, Joop, Helms, Martine, Aiking, Harry, 2006. Protein consumption and sustainability: diet diversity in EU-15. Ecol. Econ. 59 (3), 267–274.

Derwent, R.G., Jenkin, M.E., Saunders, S.M., Pilling, M.J., 1998. Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism. Atmos. Environ. 32, 2429–2441.

Duchin, F., 2005. Sustainable consumption of food. A framework for analysing scenarios about changes in diets, in. J. Ind. Ecol. 9 (1–2), 99–114.
EFSA, 2008. Food Based Dietry Guidelines. Scientific Opinion of the Panel on Dietetic Products, Nutrition and Allergies. Question No EFSA-Q-2005-015c). 5 (Agreed on 2 July 2008 for release for public consultation European Food Safety Authority.
EUROSTAT, 2008. Eurostat Manual of Supply, Use and Input-Output Tables. EUROSTAT, Luxembourg, Luxembourg.
Eurostat, 2010. Household Consumption Expenditureavailable via: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Household_consumption_expenditure (accessed 7 May 2010).
Flynn, A., Wiedrnann, T., Barrett, J., Collins, A., 2006. The environmental impacts of consumption at a subnational level—the ecological footprint of Cardiff. J. Ind. Ecol. 10 (3), 9–24.
Girod, B., de Haan, P., 2010. More or better? A model for changes in household greenhouse gas emissions due to higher income. J. Ind. Ecol. 14 (1), p31–p49.
Goedkoop, M., Spriensma, R., 1999. The Eco-indicator 99. A damage oriented method for life cycle impact assessment. Methodology Report and Annex. Pré Consultants, Amersfoort, The Netherlands http://www.pre.nl/eco-indicator99/.
Goedkoop, Mark, Heijungs, Reinout, Huijbregts, Mark, De Schryver, An, Struijs, Jaap, van Zelm, Rosalie, 2009. ReCiPe 2008, A Life Cycle Impact Assessment Method which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint LevelFirst edition. Environment Ministry, Den Haag, Netherlands.
Goodland, R., 1995. Environmental sustainability in agriculture: diet matters. Ecol. Econ. 23, 189–200.
Guinée, J.B., 2002. In: Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., De Koning, A., Van Oers, L., Wegener Sleeswijk, A., Suh, S., de Haes HA, Udo, De Bruijn, J.A., Van Duin, R., Huijbregts, M.A.J. (Eds.), Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Series: Eco-efficiency in Industry and Science. Kluwer Academic Publishers, Dordrecht.
Hardin-Fanning, F., 2008. The effects of a Mediterranean-style dietary pattern on cardiovascular risk. Nurs. Clin. North Am. 43 (1), 105–115.
Health Council of the Netherlands, 2006. Guidelines for a Healthy Diet 2006. Health Council of the Netherlands, The Hague.
Heijungs, R., Suh, S., 2002. The Computational Structure of Life Cycle Assessment. Kluwer Academic Publishers1-4020-0672-1.
Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A., Ansems, A.M.M., Eggels, P.G., van Duin, R., de Goede, H.P., 1992. Environmental Life Cycle Assessment of products. Guide and Backgrounds. Centre of Environmental Science (CML), Leiden University, Leiden.
Heijungs, R., De Koning, A., Suh, S., Huppes, G., 2006. Toward an information tool for integrated product policy: requirements for data and computation. J. Ind. Ecol. 10 (3), 147–158.
Hendrickson, C.T., Lave, L.B., Matthews, H.S., 2006. Environmental Life Cycle Assessment of Goods and Services: An Input–Output Approach. Resources for the Future Press, Washington D.C.
Hertwich, E.G., 2005. Lifecycle approaches to sustainable consumption: a critical review. Environ. Sci. Technol. 39 (13), 4673–4684.
Hertwich, Edgar G., van der Voet, Ester, Suh, Sangwon, Tukker, Arnold, Huijbregts, Mark, Kazmierczyk, Pawel, Lenzen, Manfred, McNeely, Jeff, Moriguchi, Yuichi, 2010. Environmental impacts of consumption and production: priority products and materials. International Panel on the Sustainable Use of Natural Resources. UNEP, Paris, France.
Huijbregts, M.A.J., 1999a. Priority assessment of toxic substances in LCA. Development and Application of the Multi-media Fate, Exposure and Effect Model USES-LCA. IVAM environmental research, University of Amsterdam, Amsterdam.
Huijbregts, M.A.J., 1999b. Life cycle impact assessment of acidifying and eutrophying air pollutants. Calculation of Equivalency Factors with RAINS-LCA. Interfaculty Department of Environmental Science, Faculty of Environmental Science, University of Amsterdam, The Netherlands.
Huijbregts, M.A.J., 2000. Priority assessment of toxic substances in the frame of LCA. Time Horizon Dependency of Toxicity Potentials Calculated with the Multi-media Fate, Exposure and Effects Model USES-LCA. Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, The Netherlands.
Huijbregts, M.A.J., Thissen, U., Guinée, J.B., Jager, T., van de Meent, D., Ragas, A.M.J., Wegener Sleeswijk, A., Reijnders, L., 2000. Priority assessment of toxic substances in life cycle assessment, I: calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effects model USES-LCA. Chemosphere 41, 541–573.
Huppes, Gjalt, de Koning, Arjan, Suh, Sangwon, Heijungs, Reinout, van Oers, Lauran, Nielsen, Per, Guinée, Jeroen B., 2006. Environmental impacts of consumption in the European union: high-resolution input-output tables with detailed environmental extensions. J. Ind. Ecol. 10 (3), 129–146.
Huppes, G., Davidson, M.D., Kuyper, J., Van Oers, L., Udo de Haes, H.A., Warringa, G., 2007. Eco-efficient environmental policy in oil and gas production in The Netherlands. Ecol. Econ. 61 (1), 43–51.
International Panel on Climate Change (IPCC), 2007. Climate change 2007: Synthesis Report. IPCC Secretariat, Geneva, Switzerland. Also available http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. (accessed 10 January 2010).
International Standardization Organisation (ISO, 2006. ISO 14040:2006 Environmental management – life cycle assessment – principles and framework. ISO, Geneva, Switzerland.
James, W.P., Duthie, G.G., Wahle, K.W., 1989. The Mediterranean diet: protective or simply non-toxic? Eur. J. Clin. Nutr. 43 (Suppl. 2), 31–41.
Jansen, B., Thollier, K., 2006. Bottom-up life-cycle assessment of product consumption in Belgium. J. Ind. Ecol. 10 (3), 41–55.
Jenkin, M.E., Hayman, G.D., 1999. Photochemical ozone creation potentials for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters. Atmos. Environ. 33, 1275–1293.
Jungbluth, N., Tietje, O., Scholz, R.W., 2000. Food purchases: impacts from the consumers' point of view investigated with a modular LCA. Int. J. Life Cycle Assess. 5 (3), 134–142.
Keys, A., 1995. Mediterranean diet and public health: personal reflections. Am. J. Clin. Nutr. 61, 1321S–1323S (Suppl).
Kushi, L.H., Lenart, E.B., Willet, W.C., 1995a. Health implications of Mediterranean diets in light of contemporary knowledge. 1. plant foods and dairy products. Am. J. Clin. Nutr. 61 (Suppl. 6), 1407S–1415S.
Kushi, L.H., Lenart, E.B., Willet, W.C., 1995b. Health implications of Mediterranean diets in light of contemporary knowledge. 2. meat, wine, fats, and oils. Am. J. Clin. Nutr. 61 (Suppl. 6), 1416S–1427S.
Lenzen, M., 2001. Errors in conventional and input–output-based life-cycle inventories. J. Ind. Ecol. 4 (4).
Lenzen, M., Dey, C.J., 2002. Economic, energy and emissions impacts of some environmentally motivated consumer, technology and government spending options. Energy Econ. 24, 377–403.
Leontief, W., Ford, D., 1970. Environmental repercussions and the economic structure: an input–output approach. Rev. Econ. Stat. 52 (3), 262–271.
Lloyd-Williams, F., O'Flaherty, M., Mwatsama, M., Birt, C., Ireland, R., Capewell, S., 2008. Estimating the cardiovascular mortality burden attributable to the European Common Agricultural Policy on dietary saturated fats. Bull. World Health Organ. 86, 535–541.
McMichael, Anthony J., Powles, John W., Butler, Colin D., Uauy, Ricardo, 2007. Food, livestock production, energy, climate change and health. Lancet 370 (9594), 1253–1263. doi:10.1016/S0140-6736(07)61256-2.
Miller, R., Blair, P.r, 1985. Input Output Analysis: Foundations and Extensions. Prentice-Hall, Englewood Cliffs, N.J., US.
Myers, Norman, Kent, Jennifer, 2004. The New Consumers: The Influence Of Affluence On The Environment. Island Press, Washington D.C., US.
Naska, A., Oikonomou, E., Trichopoulou, A., Wagner, K., Gedrich, K., 2007. Estimations of daily energy and nutrient availability based on nationally representative household budget survey data. The Data Food Networking (DAFNE) project. Public Health Nutr. 10, 1422–1429.
Nielsen, A.M., Weidema, B.P., Dalgaard, R., Halberg, N., 2003. LCA food data base. www.lcafood.dk.
Nijdam, D.S., Wilting, H.C., Goedkoop, M.J., Madsen, J., 2005. Environmental load from Dutch private consumption: how much damage takes place abroad? J. Ind. Ecol. 9 (1–2), 147–168.
Oers L van, Huijbregts, M., Huppes, G., Koning A de, Suh, S. (Eds.), 2001. LCA normalization data for the Netherlands 1997/1998, Western Europe 1995 and the World 1990 and 1995. RIZA Lelystad and CML, Leiden University, Leiden, The Netherlands. data downloadable from http://www.leidenuniv.nl/cml/lca2/index.html.
Palm, V., Wadeskog, A., Finnveden, G., 2006. Swedish experience using environmental accounts data for integrated product policy issues. J. Ind. Ecol. 10 (3), 57–72.
Pitesky, M., Stackhouse, K.R., Mitloemer, F.M., 2009. Clearing the air: livestock's contribution to climate change. Adv. Agronomy 103, 1–36.
Ramachandran, A., Snehalatha, C., 2004. Diabetes mellitus. In: Gibney, M.J., Marghetts, B.M., Kearney, J.M., Arab, L. (Eds.), Public Health Nutrition. The nutrition society, Backwell Science, pp. 330–340.
Reijnders, L., Soret, S., 2003. Quantification of the environmental impact of different dietary protein choices. Am. J. Clin. Nutr. 78, 664S–668S (suppl).
Stehfest, E., Bouwman, L., van Vuuren, D.P., den Elzen, M.G.J., Eickhout, B., Kabat, P., 2009. Climate benefits of changing diet. Climatic Change 95, 83–102.
Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's Long Shadow. Environmental Issues and Options. Food and Agriculture Organization of the United Nations, Rome, Italy.
Stern, N., 2006. The Economics of Climate Change. The Stern Review. Cambridge University Press, Cambridge, UK.
Suh, S., 2004. Materials and energy flows in industry and ecosystem networks : life cycle assessment, input–output analysis, material flow analysis, ecological network flow analysis, and their combinations for industrial ecology. Dissertation Leiden University90-9018192-X.
Ten Raa, T., 2005. The Economics of Input–Output Analysis. Cambridge University Press.
Tilman, D., 1999. Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. Proc. Natl. Acad. Sci. U. S. A. 96, 5995–6000.
Trichopoulou, A., 2001. The Mediterranean diet: the past and the present. Nutr. Metab. Cardiovasc. Dis. 11 (4 Suppl.), 1–4.
Trichopoulou, A., Critselis, E., 2004. Mediterranean diet and longevity. Eur. J. Cancer Prev. 13 (5), 453–456.
Trichopoulou, A., Vasilopoulou, E., 2000a. Mediterranean diet and longevity. Br. J. Nutr. 84 (Suppl. 2), S205–S209.
Trichopoulou, A., Vasilopoulou, E., 2000b. Mediterranean diet and longevity. Br. J. Nutr. 84 (Suppl. 2), S205–S209.
Trichopoulou, A., Naska, A., Oikonomou, E., 2005. The DAFNE databank: the past and future of monitoring the dietary habits of Europeans. J. Public Health 13, 69–73.
Tukker, A., Jansen, B., 2006. Environment impacts of products—a detailed review of studies. J. Ind. Ecol. 10 (3), 159–182.
Tukker, A., Huppes, G., Guniee, J., Heijungs, R., de Koning, A., van Oers, L., Suh, S., Geerken, T., Van Holderbeke, M., Jansen, B., Nielsen, P., Eder, P., Delgado, L., 2006. Environmental Impact of Products (EIPRO). EUR22284EN. EC Joint Research Centre—IPTS, Seville http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1429.
Tukker, Arnold, Sandra Bausch-Goldbohm, Marieke Verheijden, Arjan de Koning, René Kleijn, Oliver Wolf, Ignacio Perez Dominguez, with support of Frederik Neuwahl

and José M. Rueda-Cantuche (2009). Environmental Impacts of Diet Changes in the EU (EI-DiC). Final Report and Annexes. Institute for Prospective Technical Studies, Sevilla, Spain, ISSN 1018-5593.
Weidema, B.P., Suh, S., Notten, P., 2006. Setting priorities within product-oriented environmental policy: the Danish perspectives. J. Ind. Ecol. 10 (3), 73–87.
Weidema, B., Wesnæs, M., Hermansen, J., Kristensen, T., Halberg, N., 2008. Environmental Improvement Potentials of Meat and Dairy Products. European Commission, DG JRC, Institute for Prospective Technological Studies. Technical report EUR 23491 EN. http://ftp.jrc.es/EURdoc/JRC46650.pdf.
WHO, 2002. The World Health Report 2002. Reducing Risks, Promoting Healthy Life. World Health Organization, Geneva.
WHO Regional Office for Europe, 2003. Food Based Dietary Guidelines in the WHO European Region. WHO, Copenhagen, Denmark.
WHO/FAO, 2003. Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation. World Health Organization, Geneva.
WMO (World Meteorological Organisation), 1992. Scientific assessment of ozone depletion: 1991. Global Ozone Research and Monitoring Project—Report no. 25. Geneva.
WMO (World Meteorological Organisation), 1995. Scientific assessment of ozone depletion: 1994. Global Ozone Research and Monitoring Project—Report no. 37. Geneva.
WMO (World Meteorological Organisation), 1999. Scientific assessment of ozone depletion: 1998. Global Ozone Research and Monitoring Project—Report no. 44. Geneva.
World Cancer Research Fund, American Institute for Cancer Research, 2007. Food, Nutrition, Physical Activity and the Prevention of Cancer: a global perspective. AICR, Washington, DC.