Effect of dietary change on greenhouse gas emissions and land use demand – The state of knowledge in 2014

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ABSTRACT

In combination with technical advances in agriculture, human dietary change is suggested to be necessary to reduce the environmental impact of the food system. In this paper a systematic review, assessing the climate and land use impacts of dietary change, is performed. The aims are to evaluate the scientific basis of dietary scenario analysis and to estimate the potential of reducing greenhouse gas emissions and land use demand by changing the composition of the diet. The review includes 14 peer-reviewed journal articles and in total 55 scenarios assessing the greenhouse gas emissions and land use demand of different diets. The results suggest that dietary change, in areas with affluent diet, could play an important role in reaching environmental goals, with up to 50% potential to reduce greenhouse gas emissions and land use demand of the current diet.

Keywords: Review, diet, scenario, climate, land use

1. Introduction

Global food production, accounts for around 30% of total anthropogenic greenhouse gas emissions (GHGE), occupies more than a third of the world´s land surface (Garnett 2011), and is identified as a great threat to the environment (EC 2006). In combination with technical advances in agriculture, changes towards more sustainable eating patterns are suggested to be a necessary to meet environmental targets (Garnett 2011).

Knowledge of sustainable food consumption is increasing with the growing number of environmental and life cycle assessments of foods, meals, and complete diets. A method commonly used to assess the impact of different dietary patterns is dietary scenario analysis. The methodological approach of dietary scenario analysis can have decisive effect on the final results. To draw general conclusions on which dietary changes that can promote a development towards more sustainable food consumption, therefore, requires that results from several studies are analyzed and compared. However, so far, few syntheses of studies assessing the environmental impact of diet have been performed.

To synthesize the state of knowledge, this paper provides a systematic review of research articles which assessed the environmental impact of dietary scenarios. The objectives are to: i) evaluate the scientific basis of scenario analyses assessing the impact on GHGE and land use demand (LUD) of human dietary change, ii) estimate the potential of reducing GHGE and LUD via dietary change and iii) identify current gaps of knowledge. The paper can be used as an overview of the state of knowledge and evidence base of sustainable food consumption in the year of 2014.

2. Method

2.1. Literature search strategy

In order to ensure scientific quality and minimize the risk of bias, the study design and analysis of this review follows the PRISMA Statement protocol (Moher et al. 2009).

The literature search was performed in February 2014 with the use of Web of Knowledge (ISI), Scopus and Google Scholar. To assess the effect of human dietary change on GHGE and LUD, the terms: 'diet' or 'food' and 'scenario' were combined with the terms 'climate' or 'greenhouse gas' or 'land' or 'sustain*'. In addition, related and relevant articles found in reference lists were reviewed. Articles included in this review meet the following six inclusion criteria: i) English-language publications; ii) published between 2005 and February 2014; iii) dietary scenario analysis is performed for a complete diet; iv) quantitative estimates of the effect on GHGE and/or LUD of human dietary change are provided; v) published in peer-reviewed scientific journals; vi) results are compared against reference scenarios of current (1990-2010) average food consumption in a specified popu-

lation. Determination of articles that meet the inclusion criteria was made based on information available in titles and abstracts of the articles. In total, 14 articles that fulfilled the inclusion criteria were identified (Fig 1).

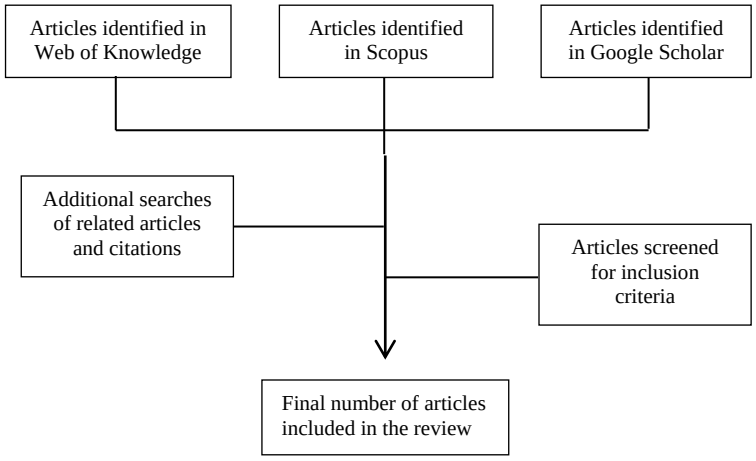

Figure 1. Literature search and selection of articles in the review

2.2. Synthesis of results

Depending on the dietary composition, scenarios were categorized into healthy diets, diets in which meat is partially replaced by plant-based foods/mixed foods/dairy products, diets in which all ruminant meat is replaced by pork and poultry, diet with balanced energy intake, vegetarian diets and vegan diets. The potential to reduce environmental impact is reported as the relative change in GHGE, expressed as tons of carbon dioxide equivalents (tCO_2e) per person per year, and LUD, expressed as square meter (m^2) per person per year, compared to the reference scenarios used in the respective studies.

3. Results

3.1. Located literature

In total, 14 articles that fulfil the inclusion criteria were identified in this assessment. Out of these 14 articles, two investigated both the effect on GHGE and LUD, two the impact of LUD only, and ten the impact of GHGE only. Five articles were published between 2009 and 2011, and nine articles between 2012 and Feb 2014 (Table 1).

In the majority of the studies the main focus is on the environmental impact of reducing or changing the consumption of meat and animal-based food (Table 2). In all articles except for Pathak et al. (2010) the effect of dietary change is studied in European populations characterized by having an affluent diet.

3.2. Potential to reduce GHGE

The impact of dietary change on GHGE from the diet is summarized in Table 2. Completely avoiding all animal-based products (vegan diet) or all meat (vegetarian diet) provides the largest potential for reducing GHGE from the diet, followed by scenarios of replacing ruminant meat by pork and poultry and eating a healthier diet.

3.3. Potential to reduce LUD

The impact of dietary change on LUD from the diet is summarized in Table 2. According to the results, a change to vegan or vegetarian diets has the largest potential to reduce the demand for agriculture land, followed by changing to a healthier diet and diets in which meat is partially replaced by plant-based food.

Table 1. Articles included in the review

Author	Publication year	Environmental indicator
Van Dooren et al.	2014	GWP, LU
Hoolohan et al.	2013	GWP
Saxe et al.	2013	GWP
Temme et al.	2013	LU
Aston et al.	2012	GWP
Berners-Lee et al.	2012	GWP
Macdiarmid et al.	2012	GWP
Meier and Christen	2012	GWP, LU
Vieux et al.	2012	GWP
Fazeni and Stenmüller	2011	GWP
Tukker et al.	2011	GWP
Arnoult et al.	2010	LU
Pathak et al.	2010	GWP
Risku-Norja et al.	2009	GWP

Table 2. Summary of results

Scenario	Reduction of GHGE (%)[a]	(n)	Reduction of LUD (%)[b]	(n)
Vegan diet	25-55	6	50-60	3
Vegetarian diet	20-55	9	30-50	2
Meat partially replaced by plant-based food	+5-0	2	15	1
Meat partially replaced by dairy products	0-5	2	-	0
Ruminant meat replaced by monogastric meat	20-35	2	-	0
Meat partially replaced by mixed food	5	2	-	0
Balancing energy intake and expenditure	0-10	2	-	0
Healthy diet	0-35	19	15-45	5

[a]Effect of dietary change on GHGE from the diet, in % of reduction in GHGE of current average diets. [b]Effect of dietary change on LUD, in % of reduction in total demand of agriculture land of the average diet. n = number of scenarios. "+" indicate an increase in GHGE alt. LUD.

4. Discussion

This review is, to our knowledge, one of the first to systematically assess the current state of knowledge of the environmental impact, expressed as changes in GHGE and LUD, of dietary change. The review includes peer-reviewed journal articles published over the past ten years.

4.1. Scientific basis

This review located 14 articles that met the inclusion criteria defined in this review. In accordance with what has been shown in Heller et al. (2013), this study illustrates that life cycle assessments (LCAs) of food is an expanding research field. Nine of the articles were published during just the two last years. Although there are still gaps in knowledge, the increased number of publications in this area has significantly contributed to a better understanding of sustainable production and consumption of food.

4.2. Potential to reduce GHGE

The results show that the potential to reduce GHGE from food consumption through dietary change can be substantial in regions with affluent diets. The reduction potential seems mainly to be dependent on the amount and type of meat and animal products included in the diet. Diets in which all meat and/or meat products are re-

moved have the lowest GHGE. However, a healthier diet including meat can, according to the results, reduce the GHGE of the diet up to 35%. The impact is, however, largely dependent on what is considered to be a healthy diet, and in five of the 19 healthy dietary scenarios the reduction potential is less than 10%. The amount of red meat, and especially ruminant meat allowed in the healthy diets seem to be the decisive parameter for the climate impact of the diet. Another reason why the results vary is that some of the healthy dietary scenarios are based on organic production, which may lead to increased GHGE compared to conventional production system (Saxe et al. 2013). The difference in climate impact between different types of meat is also demonstrated by the results from the studies including scenarios where meat consumption is reduced or changed. Replacing all ruminant meat by poultry and pork can reduce the GHGE by up to 35%. Moderate reduction (up to 20%) in total meat intake (including white meat), in contrast, seems to have a negligible effect. In addition, the climate impact of the diet is, to a large extent, dependent on which foods that replace the meat, therefore, consumption of meat substitutes with high climate impact, such as cheese and air transported fruit and vegetables, should be restricted (Carlsson-Kanyama and Gonzalez 2009). Only eating necessary amounts of food has been identified as another priority measure to reduce GHGE from the diet (Garnett 2011) that also would be beneficial for health. Balancing the energy intake and expenditure can, according to the results in this review, reduce the climate impact of the diet by 0-10%, depending on the assumed energy requirements.

The GHGE from the reference scenarios, i.e. the current average diets in the studied populations, ranged from 0.9-1.7 and 1.5-3.2 tons (1.0 tons for Indian diet) of CO_2e per capita per year in the studies accounting for emissions up to farm gate and retail, respectively. The annual GHGE for the average EU citizen are around nine tons of CO_2e (EEA, 2012), which means that food consumption is responsible for about 15-35% of the total climate impact. Based on the these figures, the potential to reduce the total per capita GHGE through dietary change is about 3-20% for a transition to a vegan or vegetarian diet and up 12% by a transition to either a healthier diet with restricted intake of red and ruminant meat, or a diet in which the meat content partially been reduced and/or red or ruminant meat has been substituted by white or monogastric meat.

4.3. Potential to reduce LUD

Also the potential to reduce the LUD from the diet through dietary change may be considerable. It should, however, be kept in mind that the impact on LUD in this paper is based on only four articles. The potential to reduce the LUD of the diet appears to be largely dependent on the amount of ruminant meat consumed. Substituting all meat with plant-based food can, according to the results, reduce the land demand from the diet by up to 60%. According to Audsley et al. (2010) a replacement of 75% of the ruminant meat with pork and poultry can reduce the land demand by 40%. Replacing half of the consumption of pork and poultry with plant-based food would, on the contrary, only reduce the LUD by 5%. A healthy diet including meat may therefore also have a large potential to free land, if the consumption of red meat is limited. Diets including ruminant meat have previously been suggested to increase the number of people that can be fed from the same land area compared to vegan diets up to the point that land limited to pasture and perennial forages has been fully utilized (Peters et al. 2007). However, maximum output of food is necessarily not the primary objective, given that released land also can be used for bioenergy production, for example (Fazeni and Steinmüller 2011). Either way, as will be discussed further, differentiation between types of land is essential to fully understand the effect of diet on LUD.

The LUD of the reference dietary scenarios ranged from 1400-2100 m^2 per capita. This can be compared to the current global per capita availability of agriculture land which is about 7000 m^2 (divided between approximately 30% arable land and 70% pasture) if global croplands are assumed to be distributed equally across the population.

4.4. Identified research gaps

4.4.1. Differentiation on individual, regional and social level

The general approach to study the impact of dietary choices by using scenario analysis is to use a reference scenario based on the average per capita consumption in the population studied. Since consumption patterns and nutritional requirements differ depending on, for example, gender, age and physical activity level, it would be interesting to see more research on specific groups of the population. It is also noteworthy that all articles re-

viewed, except one, study the impact of dietary change in European countries/regions characterized by having affluent diets. To understand the impact of dietary change in a broader and global perspective similar studies are required in countries/regions with different habits, culture and conditions.

4.4.2. Differentiation of plant-based scenarios

Previous findings suggest that that plant-based food consumption based on self-selected diets tend to have a higher climate impact compared to plant-based consumption in hypothetical scenarios (Vieux et al. 2012). In plant-based hypothetical dietary scenarios, meat is often replaced by unprocessed foods such as pulses, cereals, salads, vegetables, fruit, nuts and seeds. Vegetarian diets are in general characterized by a higher proportion of these food groups (Craig 2010; Key et al. 2006), however, processed plant-based meat substitutes (e.g. processed soy, quorn, tofu, and tempeh) represent an increasingly important component of modern plant-based diets. The environmental impact of such processed vegetarian meat substitutes has so far only been investigated in a limited number of studies (Blonk et al. 2008; Davis et al. 2010; Finnagan 2010a; Finnigan et al. 2010b; Leuenberger et al. 2010; Nijdam et al. 2012; Nonhebel and Raats 2007; Xueqin and Ierland 2004). The results indicate that these products may have relatively high energy demands due to the higher degree of processing but a lower climate and overall environmental impact, in comparison to most types of meat. Few of the reviewed articles specify that these types of processed meat substitutes are included in the dietary scenarios. The potential and limitations for reducing the environmental impact of the diet through increased consumption of this group of food products requires further analysis.

4.4.3. Differentiation of agricultural land

Current global food supply is mainly dependent on cultivated land (Johansson 2005) why the pressure on agricultural land is especially intense on cropland. Previous studies indicate that dietary change, in particular, has the potential to free pasture land (Hallström et al. 2011). Of the land released through reductions and changes in meat consumption, for example, only 5-10% is estimated to consist of cropland (Hallström 2013). Others suggest that replacing beef with pork and poultry even may increase the total demand of cropland (Audsley et al. 2010). A net gain in cropland is also not obvious if consumption of dairy products is replaced by plant-based food or when monogastric meat is replaced by processed vegetarian meat substitutes (Audsley et al. 2010; Stehfest et al. 2009).

If the distinction is not made between different types of land, there is thus a risk of overestimating the land areas suitable for agriculture that can be released by reducing ruminant meat consumption as only a limited share of pasture land is suitable for cultivation. To avoid a situation where demand for agriculture land is exported to other countries where it might increase the risk for deforestation and other negative impacts connected to increased land use pressure, it may also be of interest to in a greater extent distinguish between domestic and foreign land use in dietary scenario analysis.

4.4.4. Accounting for uncertainty

Despite the knowledge of the uncertainty related to environmental and life cycle assessments, the environmental impact of dietary scenarios is in general reported in absolute numbers without standard deviations. This is questionable as it makes it difficult to evaluate the reliability of the results. According to the ISO standard, the interpretation phase in LCAs should include an evaluation of the completeness, sensitivity and compliance of the analysis (ISO 2006). This is required in order to help the reader to determine what conclusions can be drawn from the results and would be useful also in dietary scenario analysis.

4.5. Strengths and limitations

To minimize bias, this review includes only peer-reviewed journal articles selected by the use of predefined inclusion criteria. The aim has been to assess the articles with a high level of objectivity and transparency. A limitation with the study is that only a small number of articles which met the inclusion criteria were located. The limited number of articles can partly be explained by the novelty of the research field but is also due to the

narrow inclusion criteria which excluded several relevant articles (Audsley et al. 2010; Eshel and Martin 2006; Kastner 2012; Macdiarmid et al. 2011; Marlow et al. 2009; Westhoek et al. 2011; Popp et al. 2010; Powell and Lenton 2012; Wirsenius et al. 2010; Stehfest et al. 2009). Relevant publications and data would perhaps also be found in non-English publications.

In this review, the majority of articles which quantify GHGE from the diet exclude emissions coming from direct and indirect land use change. The exceptions are Meier & Christensen (2012) and Holohan et al. (2013) who include GHGE from deforestation resulting from livestock supply chains. Greenhouse gas emissions from direct and indirect land use change are suggested to have substantial impact on the climate impact from agricultural products (Cederberg et al., 2011; Ponsioen and Blonk, 2012; Schmidinger & Stehfest, 2012), which means that the results on GHGE in this review may be underestimated.

The climate impact of diet is quantified based on the global warming potential (GWP) of GHE. In the fifth IPCC assessment report published in 2013 (Myhre et al. 2013) the GWP of methane over a time horizon of 100 years was increased from previously 25 to 34 kg CO_2e per kilograms of emissions. This review includes articles published before the new IPCC report was published and therefore use the lower GWP for methane in their calculations. This means that the climate impact of diets containing ruminant meat is likely to be higher than the results shown by this review.

In this paper the environmental impact of dietary scenarios is assessed only based on the emissions of GHGE and demand of agriculture land. These aspects can often, but not always, serve as indicators of other environmental impact categories such as eutrophication, acidification and loss of biodiversity (Rockström et al. 2009; Röös et al. 2013; van Dooren et al. 2014). However, for a full assessment of the environmental impact of the diet other environmental impact categories also have to be included. Within the wide concept of sustainable food production and consumption also several other aspects, of ecological, social and economic dimensions are included (FAO 2013). These aspects, however, go beyond the scope of this paper. In future studies interdisciplinary and holistic assessments of the diet which include more sustainability aspects are required.

5. Conclusion

This systematic review evaluates the potential of dietary change as a measure for more sustainable food systems. The results suggest that dietary change, in areas with affluent diet, can play an important role in reaching environmental goals, with up to 50% potential to reduce GHGE and LUD of the current diet. The reduction potential mainly depends on the amount and type of meat included in the diet but also on the environmental performance of the food substituting meat. In future research interdisciplinary and holistic assessments of the diet including more sustainability aspects are required. Improved knowledge is also needed on the uncertainty in dietary scenario studies, the environmental impact of substitutes and complements to meat, and the effect of dietary change in different groups of populations and geographical regions.

6. References

Arnoult M, Jones P, Tranter R, Tiffin R, Traill W, Tzanopoulos J (2010) Modelling the likely impact of healthy eating guidelines on agricultural production and land use in England and Wales. Land Use Policy 27: 1046-1055

Aston LM, Smith JN, Powles JW (2012). Impact of a reduced red and processed meat dietary pattern on disease risks and greenhouse gas emissions in the UK: a modelling study. BMJ Open 2 (5): http://dx.doi.org/10.1136/bmjopen-2012-001072

Audsley E, Angus A, Chatterton JC, Graves A, Morris J, Murphy-Bokern D, Pearn KR, Sandars DL, Williams AG (2010) Food, land and greenhouse gases. The effect of changes in UK food consumption on land requirements and greenhouse gas emissions. Report for the Comitte of Climate Change, Cranfield University. Available at:
https://dspace.lib.cranfield.ac.uk/bitstream/1826/6496/1/CCC_Food_land_and_GHG_Sep%202011.pdf (accessed 2014-02-27).

Berners-Lee M, Hoolohan C, Cammack H, Hewitt CN (2012) The relative greenhouse gas impacts of realisticdietary choices. Energ Policy 43: 184-190

Blonk H, Kool A, Luske B, de Waart S (2008) Environmental effects of protein-rich food products in the Netherlands Consequences of animal protein substitutes. Blonk Milieu Advies, Gouda

Carlsson-Kanyama A, Gonzalez AD (2009) Potential contributions of food consumption patterns to climate change. Am J Clin Nutr 89: S1704-S1709

Cederberg C, Persson UM, Neovius K, Molander S, Clift R (2011). Including Carbon Emissions from Deforestation in the Carbon Footprint of Brazilian Beef. Env Sci Tech 45: 1773-1779

Craig WJ (2010) Nutrition Concerns and Health Effects of Vegetarian Diets. Nutr Clin Pract 25: 613-620

Davis J, Sonesson U, Baumgartner DU, Nemecek T (2010) Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. Food Res Int 43: 1874-1884

Eshel G, Martin PA (2006) Diet, Energy, and Global Warming. Earth Interac 10: 1-17

European Commission (EC) (2006) Environmental impact of products (EIPRO): Analysis of the life cycle environmental impacts related to the total final consumption of the EU25. European Commission Technical Report. EUR 22284 EN.

European Environment Agency (EEA) (2012) Greenhouse gas emissions trends and projections in Europe 2012. Tracking progress towards Kyoto and 2020 targets. EEA report No 6/2012, Copenhagen

Fazeni K, Steinmüller H (2011) Impact of changes in diet on the availability of land, energy demand, and greenhouse gas emissions of agriculture. Energ Sustain Soc 1: 1-14

Finnagan T (2010a) Food 2030 Life cycle analysis and the role of quorn foods within the new fundamentals of food policy. Summary document. Available at: http://www.mycoprotein.org/assets/timfinniganfood2030.pdf (accessed 2014-02-27).

Finnigan T, Lemon M, Allan B, Paton I (2010b) A scoping study towards an LCA for Quorn mince. SeventhInternational Conference on Life Cycle Assemessment in the Agri-Food Sector, Sep 22-24, 2010, Bari

Food and Agriculture Organisation (FAO) (2013) Sustainable food consumption and production. FAO. Rome

Garnett T (2011) Where are the best opportunities for reducing greenhouse gas emissions in the food system(including the food chain)? Food Policy 36: S23-S32

Hallström E, Ahlgren S, Börjesson P (2011) Challenges and opportunities for future production of food, feed and biofuel- A land use perspective. Report No 74. Department of Environmental and Energy Systems Studies, Lund University, Lund

Hallström E (2013) Dietary change for sustainable food systems. Effects on climate, land use and health. Environmental and energy system studies. Lund University, Lund

Heller MC, Keoleian GA, Willett WC (2013) Toward a Life Cycle-Based, Diet-level Framework for Food Environmental Impact and Nutritional Quality Assessment: A Critical Review. Envl Sci Tech 47: 12632-12647

Hoolohan C, Berners-Lee M, McKinstry-West J, Hewitt CN (2013) Mitigating the greenhouse gas emissions embodied in food through realistic consumer choices. Energ Policy 63: 1065-1074

International Organisation for Standardisation (ISO) (2006) Environmental management. Life cycle assessment - Requirements and guidelines. ISO 14044, ISO, Geneva

Johansson S (2005) The Swedish Foodprint. An Agroecological Study of Food Consumption. Department of Ecology and Crop Production Science, Swedish University of Agriculutral Sciences, Uppsala

Kastner T (2012) Changes in human food and wood consumption and their impacts on global land demand, Center for Energy and Environmental Studies. University of Groningen, Groningen

Key TJ, Appleby PN, Rosell MS (2006) Health effects of vegetarian and vegan diets. P Nutr Soc 65: 35-41

Leuenberger M, Jungbluth N, Büsser S (2010) Environmental impact of canteen meals: comparison of vegetarian and meat based recipes. Seventh International Conference on Life Cycle Assemessment in the Agri-Food Sector, Sep 22-24, 2010, Bari

Marlow HJ, Hayes WK, Soret S, Carter RL, Schwab ER, Sabate J (2009) Diet and the environment: does what you eat matter? Am J Clin Nutr 89: S1699-S1703

Macdiarmid J, Kyle J, Horgan G, Loe J, Fyfe C, Johnstone A, McNeill G (2011) Livewell: a balance of healthy and sustainable food choices. WWF, London

Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A, McNeill G (2012) Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? Am J Clin Nutr 96:632-639

Meier T, Christen O (2012) Environmental impacts of dietary recommendations and dietary styles: Germany as an example. Env Sci Tech 47: 877-888

Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Ann Intern Med 151: 264-269

Myhre G, Shindell D, Bréon F-M, Collins W, Fuglestvedt J, Huang J, Koch D, Lamarque J-F, Lee D, Mendoza B, Nakajima T, Robock A, Stephens G, Takemura T, Zhang H (2013) Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgles PM. (Eds.) Cambridge University Press, New York

Nonhebel S, Raats J (2007) Environmental impact of meat substitutes: Comparison between quorn and pork. Fifth International Conference on Life Cycle Assemessment in the Agri-Food Sector, April 25–26, 2007, Gothenburg

Nijdam D, Rood T, Westhoek H (2012) The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 37: 760-770

Pathak H, Jain N, Bhatia A, Patel J, Aggarwal PK (2010) Carbon footprints of Indian food items. Agr Ecosystem Env 139: 66-73

Peters CJ, Wilkins JL, Fick GW (2007) Testing a complete-diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: The New York State example. Renew Agr Food Syst 22: 145-153

Ponsioen TC, Blonk TJ (2012) Calculating land use change in carbon footprints of agricultural products as an impact of current land use. J Clean Prod 28: 120-126

Popp A, Lotze-Campen H, Bodirsky B (2010) Food consumption, diet shifts and associated non-CO greenhouse gases from agricultural production. Global Env Change 20: 451-462

Powell TWR, Lenton TM (2012) Future carbon dioxide removal via biomass energy constrained by agricultural efficiency and dietary trends. Energ Env Sci 5: 8116-8133

Risku-Norja H, Kurppa S, Helenius J (2009) Dietary choices and greenhouse gas emissions - assessment of impact of vegetarian and organic options at national scale. Prog Ind Ecol Int J 6: 340-354

Rockstrom J, Steffen W, Noone K, Persson A, Chapin FS, Lambin E, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sorlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson, K, Crutzen P, Foley J (2009) Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecol Soc 14: 1-33

Röös E, Sundberg C, Tidåker P, Strid I, Hansson PA (2013). Can carbon footprint serve as an indicator of the environmental impact of meat production? Ecol Indicators 24: 573-581

Saxe H, Larsen T, Mogensen L (2013) The global warming potential of two healthy Nordic diets compared with the average Danish diet. Climatic Change 116: 249-262

Schmidinger K, Stehfest E (2012) Including CO2 implications of land occupation in LCAs—method and example for livestock products. Int J LCA 17: 962-972

Stehfest E, Bouwman L, van Vuuren DP, den Elzen, MGJ, Eickhout B, Kabat P (2009) Climate benefits of changing diet. Climatic Change 95: 83-102

Temme EH, van der Voet H, Thissen JT, Verkaik-Kloosterman J, van Donkersgoed G, Nonhebel S (2013) Replacement of meat and dairy by plant-derived foods: estimated effects on land use, iron and SFA intakes in young Dutch adult females. Pub Health Nutr 16: 1900-1907

Tukker A, Goldbohm RA, de Koning A, Verheijden M, Kleijn R, Wolf O, Perez-Dominguez I, Rueda-Cantuche JM (2011) Environmental impacts of changes to healthier diets in Europe. Ecol Econ 70: 1776-1788

van Dooren C, Marinussen M, Blonk H, Aiking H, Vellinga P (2014) Exploring dietary guidelines based onecological and nutritional values: A comparison of six dietary patterns. Food Policy 44: 36-46

Vieux F, Darmon N, Touazi D, Soler LG (2012) Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? Ecol Econ 75: 91-101

Westhoek H, Rood T, van den Berg M, Janse J, Nijdam D, Reudink M, Stehfest E (2011) The protein puzzle. The consumption and production of meat, dairy and fish in the European Union. PBL. Netherlands Environment Agency, The Hague

Wirsenius S, Azar C, Berndes G (2010) How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agr Syst 103: 621-638

Xueqin Z, Ierland ECV (2004) Protein Chains and Environmental Pressures: A Comparison of Pork and Novel Protein Foods. Environ Sci 1: 254-276

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