Dietary change for sustainable food systems: Effects on climate, land use and health

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Abstract

Food production and consumption are key drivers of environmental pressures and are essential factors in the promotion and maintenance of health. Production of food occupies more than 1/3 of global land areas and is estimated to be responsible for some 30% of global greenhouse gas emissions. At the same time, we live in a world where nearly one billion people go hungry and even more people suffer from health problems related to overweight and obesity. This raises the question about sustainability of the current food systems.

In this thesis the potential of dietary change as a measure to reduce environmental impact and increase health is analyzed with special attention to uncertainty aspects in the data and methods used. The results illustrate that awareness of the variability and uncertainty in the data and methods used may be crucial for a proper use and interpretation of results in sustainability studies of food and diets. It is further suggested that dietary change, in areas with unrestricted diet, could play an important role in reaching environmental and health goals, with up to a 50% potential to reduce GHG emissions and land use demand of the diet. The potential to improve sustainability of the food system through dietary change can be substantial and mainly depends on the amount and type of meat included in the diet.

Further understanding of dietary change as a measure of more sustainable food systems requires interdisciplinary and holistic assessments of the diet, including more sustainability aspects. There is also need for improved knowledge of the environmental impact of substitutes and complements for meat, of the effect of dietary change in different geographical regions, of the uncertainties in dietary scenario studies and of policy instruments that can facilitate the transition towards more sustainable diets.

Key words
Diet, meat, climate impact, land use, nutrition, health

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Abstract

Food production and consumption are key drivers of environmental pressures and are essential factors in the promotion and maintenance of health. Production of food occupies more than 1/3 of global land areas and is estimated to be responsible for some 30% of global greenhouse gas emissions. At the same time, we live in a world where nearly one billion people go hungry and even more people suffer from health problems related to overweight and obesity. This raises the question about the sustainability of the current food systems.

In this thesis the potential of dietary change as a measure to reduce environmental impact and increase health is analyzed with special attention to uncertainty aspects in the data and methods used. The results illustrate that awareness of the variability and uncertainty in the data and methods used may be crucial for a proper use and interpretation of results in sustainability studies of food and diets. It is further suggested that dietary change, in areas with unrestricted diet, could play an important role in reaching environmental and health goals, with up to a 50% potential to reduce GHG emissions and land use demand from the diet. The potential to improve sustainability of the food system through dietary change can be substantial and mainly depends on the amount and type of meat included in the diet.

Further understanding of dietary change as a measure of more sustainable food systems requires interdisciplinary and holistic assessments of the diet, including more sustainability aspects. There is also need for improved knowledge of the environmental impact of substitutes and complements for meat, of the effect of dietary change in different geographical regions, of uncertainties in dietary scenario studies and of policy instruments that can facilitate the transition towards more sustainable diets.

Populärvetenskaplig sammanfattning

Vilken typ av mat vi konsumerar och hur den produceras har stor inverkan på vår miljö och hälsa. Den globala livsmedelsproduktionen ockuperar drygt en tredjedel av världens markyta, står för runt 30 % av den totala klimatpåverkan och är identifierad som ett av de största hoten mot vår miljö. Vi lever också i en värld där nästan en miljard människor går hungriga och ännu fler lider av problem relaterade till övervikt och fetma. Mot denna bakgrund är det lätt att ifrågasätta hållbarheten i dagens livsmedelssystem.

Målet med det här arbetet har varit att bidra till ny kunskap om hur hållbarheten i dagens livsmedelssystem kan förbättras. Avhandlingen innehåller två artiklar som främst fokuserar på följande två frågeställningar:

I) *Vilka metodaspekter är viktiga vid bedömning av miljö- och hälsoeffekter av dieter?*

II) *Hur kan förändrade matvanor påverka dietens klimatpåverkan, markbehov och näringsinnehåll?*

För att beräkna matens miljöpåverkan används livscykelanalys medan hälsopåverkan uppskattas från näringsinnehållet i olika livsmedel. Miljö- och hälsopåverkan från olika dieter analyseras därefter med hjälp av scenarier då dessa data kombineras med verkliga och möjliga konsumtions- och produktionsmönster. Effekten av förändrade matvanor utvärderas i jämförelse med miljö- och hälsopåverkan från dagens matvanor samt uppsatta miljömål och näringsrekommendationer.

För att besvara frågeställning I analyseras hur val av data, metod och antagande kan påverka beräkningar av miljö- och hälsoeffekter från dieten. Resultaten visar att medvetenhet om variationer och osäkerheter i data och metoder kan vara avgörande för en korrekt användning och tolkning av resultaten. Statistik för hur mycket kött vi äter kan exempelvis redovisa dubbelt så hög konsumtion om den beskriver den tillgängliga mängden rått kött inklusive ben jämfört med om den beskriver den uppätna mängden tillagat kött.

Analysen av frågeställning II visar att förändrade matvanor kan minska klimatpåverkan och markbehovet från vår diet med upp till 50 % och samtidigt bidra till en bättre hälsa. Enligt resultaten beror potentialen för att minska miljöpåverkan från dieten främst på hur mycket och vilken typ av kött kosten innehåller men också på vilken typ av livsmedel vi väljer att ersätta en minskad köttkonsumtion med.

List of publications

I. **Hallström, E.**, Börjesson, P. (2013). Meat consumption statistics: reliability and discrepancy. *Sustainability: Science, Practice, & Policy 9 (2).* Published online Jul 11, 2013. http://sspp.proquest.com/archives/vol9iss2/1203-008.hallstrom.html

II. **Hallström, E.**, Röös, E., Börjesson, P. (2013) Sustainable meat consumption: a quantitative analysis of nutritional intake, greenhouse gas emissions and land use from a Swedish perspective. *Submitted.*

Author´s contribution to the publications

I. I was responsible for the study design, analysis and writing of the paper under supervision of Pål Börjesson.

II. I contributed to the study design, analysis and writing of the paper and was responsible for the quantification and analysis of nutritional intake. Elin Röös was responsible for the quantification of greenhouse gas emissions and land use demand as well as the Monte Carlo analysis. Valuable input was received from Pål Börjesson.

Contents

1 Introduction

1.1 Background

Food consumption has been identified as one of the most important drivers of environmental pressures (EC, 2006) and is an essential factor in the promotion and maintenance of health (WHO/FAO, 2003). The following sections provide a background of the impact of food production and consumption on climate, land use, nutrition and health, the main aspects that form the basis for the research in this thesis.

1.1.1 Climate change

Due to human activities global greenhouse gas (GHG) emissions per year have increased by 70% during the past 40 years (IPCC, 2007). To meet international climate goals, set to reduce the risk of adverse effects from climate change, global GHG emissions need to be cut by 50% by 2050 compared to levels in 1990 (EC 2007, UNEP, 2010). This will require substantial mitigation efforts on all fronts, not least in the food sector.

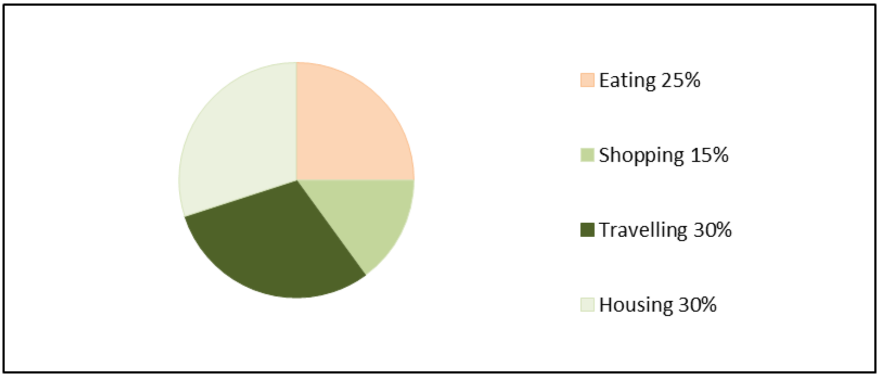

Figure I. Greenhouse gas emissions from Swedish private consumption in 2003 (80 Mtons of CO_2e, equal to 80% of total consumption based* emissions in Sweden). (SEPA, 2008).

On the global scale the agricultural sector is estimated to be responsible for 10-12% of global anthropogenic GHG emissions. If emissions from land use change, e.g. deforestation due to expanding agricultural areas and emissions produced beyond the farm gate, the GHG emissions from the food sector account for some 30% of global emissions, or more (Garnett, 2011). Greenhouse gas emissions embodied in the diet in developed countries are in the range of 2-3 tons of carbon dioxide equivalents (CO_2 eq.) per capita and year (Berners-Lee et al. 2012, Nilsson et al. 2011), equivalent to about 15-30% of the overall national emissions in high income countries (Fig I) (Garnett, 2011).

Meat is identified as the food group responsible for most GHG emissions attributable to the food sector (Carlsson-Kanyama and Gonzalez, 2009, Garnett, 2011). The livestock sector is estimated to be responsible for 18% of global GHG emissions (including emissions from land use change), a share bigger than that of transportation (Steinfeld et al., 2006).

1.1.2 Land use

Population growth in combination with more resource-demanding lifestyles is driving an increasing competition for global land resources. Pressure on land availability is associated with various environmental and societal concerns, such as increased risk of deforestation, land degradation, loss of biodiversity and food insecurity.

Global land areas are used for agriculture (37%, 5000 Mha), forest (30%, 4000 Mha), urban areas (< 1%, 40 Mha) and other land (31%, 4400 Mha) which consists of land categories such as deserts, polar areas, unvegetated and inhabited land, wet lands and inland water (FAO, 2006). The largest part of agricultural land globally consists of permanent meadows and pastures (61%, 3400 Mha) and the remaining agriculture land consists of cultivated and temporarily fallow land areas (31%, 1500 Mha).

Several of the world's major crops are used as feedstock in various sectors including food, feed and fuel production. Data from the literature suggest that globally about 2-3% of cultivated land areas are used for production of biofuels, one third is used for feed production and almost two thirds for crops dedicated to direct human consumption, i.e. plant-based crops that are not used as feed but consumed by humans directly (Fig II) (Hallström et al., 2011).

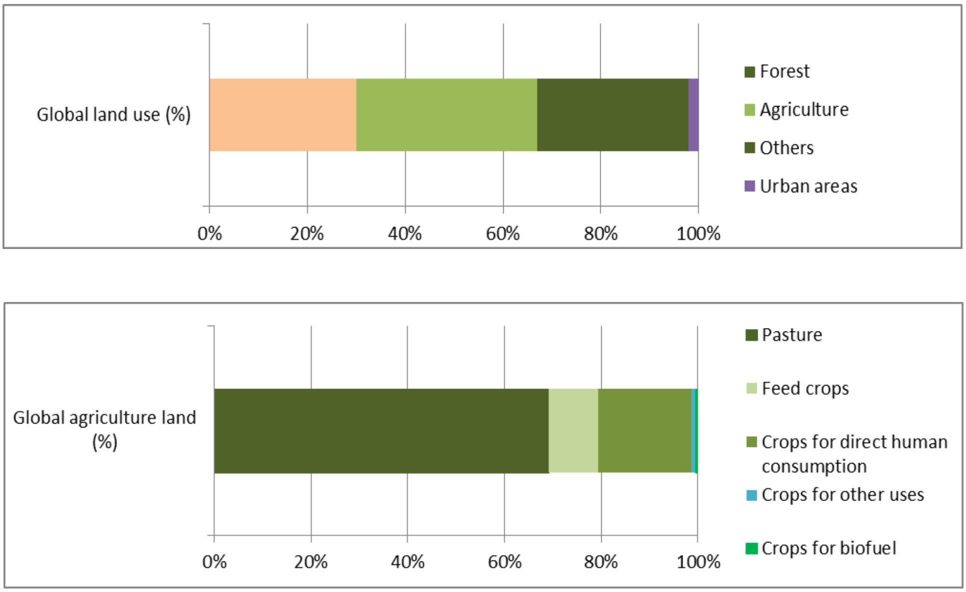

Figure II. Distribution of global agricultural land (Hallström et al., 2011)

1.1.3 Nutrition and health

Nutrition-related health problems can be due to inadequate, unbalanced or excessive food consumption. Currently one in eight people in the world do not get enough food to maintain health (WFP, 2013). At the same time energy-dense diets and sedentary lifestyles have resulted in a global epidemic of overweight and obesity, affecting 35% of the global adult population (WHO, 2011).

A healthy diet is characterized by a varied food intake with plenty of vegetables, fruits, legumes, whole grains, nuts and fish, and a restricted intake of refined grains and sugars (e.g. cakes, soda and candy), salt, red meat (pork, beef, and lamb) and processed meat products (bacon, salami, sausages, hot dogs etc.). Furthermore, the body´s energy balance, i.e. to balance the calories consumed and the calories used, is an important rule of thumb for healthy food habits (WHO/FAO, 2003, WCRF/AICR, 2007).

The recommendations for healthy food habits align well with suggested measures for reducing the environmental impact of the diet, which include eating less meat and more plant-based sources of protein and eating no more than needed to maintain a healthy body weight (Garnett, 2011). The synergies suggest that adoption of healthy diets could offer multiple benefits, including improved health in the population in general and reduced environmental impact (Fig III). Restricted consumption of meat in favor of plant-based foods in particular is believed to bring potential benefits in affluent regions (Friel et al., 2009, Tukker et al., 2011).

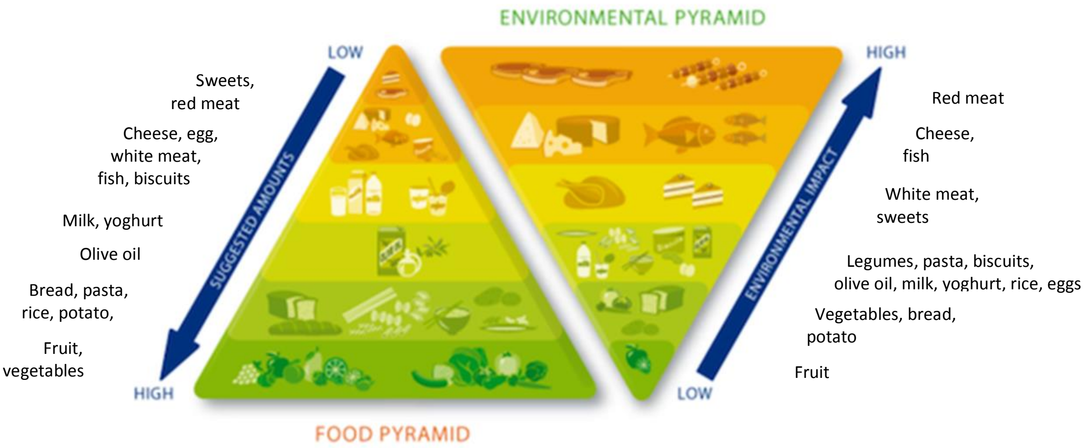

Figure III. Synergies between healthy (food pyramid) and environmentally friendly (environmental pyramid) food habits. Figure adapted from Barilla Centre for Food & Nutrition (2012)

1.2 Research objectives

The point of departure of this thesis work is the observation that the current food system is not sustainable, neither from an ecological nor a health perspective. The hypothesis, which has been the cornerstone and driving force of this work, is that sustainability in the current food system can be improved through changes in the way of producing and consuming food.

The overall objective of this thesis is to contribute to the knowledge of how sustainability in the food system can be improved. The main focus has been on methodological aspects of importance when integrating environmental, nutritional and health aspects in sustainability assessments of food and to study the environmental, resource and health effects of scenarios of dietary change.

1.2.1 Objectives of paper I

In paper I the production, presentation and use of meat consumption statistics is analyzed. The topic is of interest because consumption statistics are often combined with data on the environmental impact or nutritional content of food in order to study the sustainability of different food patterns. The paper describes aspects of importance for a proper use and interpretation of meat consumption data in such subsequent analyses.

The objectives of the paper are to i) describe methods for producing meat consumption statistics and discuss their limitations and strengths, ii) identify uncertainties in the statistics and estimate their individual impact, iii) outline and compare how relevant data are produced and presented at the national (Swedish), regional (Eurostat), and international (FAOSTAT) levels, iv) analyze the consequences of identified uncertainties and discrepancies for estimating environmental and health effects of meat consumption and v) suggest improvements in the methodology for the production, presentation, and handling of meat consumption statistics.

1.2.2 Objectives of paper II

Paper II analyzes the implications of limiting Swedish meat consumption in accordance with dietary recommendations. The potential to reduce the environmental impact through dietary change as well as the effect on nutrient intake is analyzed in order to identify beneficial interdisciplinary synergies for more sustainable food consumption patterns.

The objectives of the paper are to quantify the impact of changes in meat consumption on i) the dietary contribution of nutrients, ii) GHG emissions and iii) land requirement.

2 Key concepts and positioning

2.1 Sustainability of food and diet

As pointed out in section 1.2 the overall objective of this thesis is to contribute to knowledge that can lead to a more sustainable production and consumption of food. However, the concept of sustainability may vary, which motivates a further elaboration of how this concept of sustainable food and diet is used and interpreted in this thesis.

The most generally recognized definition of the sustainability concept was coined in the UN report "Our Common Future", better known as the Brundtland report. Sustainable development can, according to this definition, be described as "*a development that meets the need of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987). Sustainability is often understood as a three-dimensional concept that includes ecological, social and economic aspects. In accordance with this interpretation, sustainable consumption and production of food reflects a holistic vision in which sustainability within these three aspects is considered in all phases throughout the food´s life cycle (FAO, 2013). In practice this means that sustainability of food can be evaluated from several different perspectives, such as on the basis of its environmental impact, resource requirement, nutritional content, health impact, acceptability, accessibility and economic value (FAO, 2011):

> *"Sustainable Diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources"*

In this thesis the intention is not to cover all these sustainability aspects of food and diet. The focus is instead limited to analyze and discuss the sustainability of food consumption and production based on its environmental impact and resource requirements as well as its effect on nutrition and health. To get a complete picture of the sustainability of food and diets, this thesis, therefore, needs to be complemented with perspectives from other angles.

2.1.1 Environmental perspective

The food we eat and waste is associated with various negative effects on the environment, for example, eutrophication, acidification, loss of biodiversity, spread of toxins and increased global warming. In Sweden, a distinction is made among sixteen different environmental quality objectives, of which several can be linked to the production and consumption of food (SEPA, 2013). This thesis analyzes the environmental impact of food only with respect to emissions of GHG. The climate impact can serve as an indicator for other environmental impacts for some foods (e.g. monogastric meat). However, there are also cases in which the climate impact is in conflict with other environmental goals (e.g. pasture-based ruminant meat) (Röös et al., 2013a). In order to assess the overall environmental impact of changes in the food system a broader analysis, including more environmental impact categories, is thus required.

The climate scenarios set up by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007) can be used to assess what can be considered as an acceptable level of emissions of anthropogenic GHG. According to the IPCC scenarios a temperature rise greater than 1.5-2°C compared to pre-industrial levels may result in adverse effects on the environment as well as future availability of food and water. Over recent centuries the average world temperature has increased by 0.7 degrees.

To avoid an increase in temperature above 1.5-2°C, global GHG emissions will have to be cut substantially, probably by at least 50% by 2050 compared to levels in 1990. In a long-term perspective, this requires that global average emissions of GHG stabilize at a level in the range of one to two tons of CO_2 eq. per capita per year (EC, 2007, UNEP, 2010). Based on this, the GHG emissions from the food are here evaluated against a theoretical level of sustainable emissions set to one and a half tons of CO_2 eq. per capita per year, which should cover all emissions from foods and other activities such as housing, transportation and other consumption. It should, however, be remembered that scenario studies analyzing the effects of increased GHG concentrations in the atmosphere, and what it takes to avoid or minimize them, are associated, as all future studies, with large uncertainties.

2.1.2 The resource perspective

Sustainable food production and consumption also implies that the demand of food is adapted to the available supply of natural resources. Already in the eighteenth century Robert Malthus expressed his concern for the ability to feed the world´s growing population within the global resource limits (Malthus, 1798). How to use and distribute finite natural resources is an issue that has been on the agenda in sustainability discussions ever since (Meadows, 1974, Rockstrom et al., 2009). In the production of food and other agricultural products, the availability of land, fresh water, phosphorus and fossil energy are examples of limited resources of importance. In this thesis the use of natural resources for food production is, however, assessed based only on the demand for agricultural land.

The use and distribution of agricultural land is of importance both from a resource, food security and environmental perspective. Global agricultural lands should provide the growing population with enough food but also contribute to the production of raw materials for other uses, such as bioenergy, fibers and chemicals. Land use change, mainly due to expansion or intensification of agricultural lands, is also linked to environmental impacts, for instance through deforestation and its effects on climate and biodiversity.

According to Rockström et al. (2009) no more than 15% of the global land surface, equivalent to approximately 2000 Mha, should be converted to cropland for a land system change operated within the planetary boundaries. Based on this and assuming that the world population will be nine billion by 2050 (UN, 2010), available land areas for long-term, sustainable cropping will be about 0.22 ha per person, which is the area used for comparison in this thesis.

2.1.3 The health perspective

Health is defined as a state of complete, physical, mental and social well-being (WHO, 1948). This thesis analyzes the nutritional aspects of food consumption, one of several parameters influencing health. Food and nutrition have a direct impact on physiological and mental functions but also affect the long-term risk of developing several non-communicable diseases. Nutritional requirements differ between population groups and individuals, and for this reason it is difficult to determine the nutritional status or give nutritional advice on an individual level without performing biochemical measurements. Therefore, a public health perspective rather than an individual perspective is applied to analyze and discuss the requirements and health impacts of food and nutritional intake. The nutritional and health effects of food consumption are analyzed on the perspective of high-income countries and therefore mainly refer to populations with unrestricted diet.

To evaluate the sustainability of dietary intake from a nutrition and health perspective, nutritional recommendations are used. Nutritional recommendations are intended for healthy persons and their main objective is to ensure a diet that provides energy and nutrients for long-term health (NCM, 2004). Three types of nutritional recommendations exist, recommendations on macronutrients, micronutrients and dietary guidelines, all of which are used here. Recommendations on macronutrients provide information on the proportions of energy that should be derived from fat and fatty acids, carbohydrates and protein to prevent nutrition-related diseases and are expressed in percentages of energy intake (E%). Recommendations on micronutrients are based on biochemical analyses and correspond to the physiological requirements of minerals and vitamins in different population groups. In addition, there are dietary recommendations for some specific food groups and nutrients which are based on observed relationships between diet and health in clinical and epidemiological studies (NCM, 2004).

To evaluate the probability of adequate nutrient intake, levels of minerals and vitamins the intake is evaluated against reference values, provided as the lowest intake level (LI), average requirement (AR) and recommended intake (RI) of nutrients. For some nutrients there are also reference values on upper levels of intake (UL). The LI corresponds to a level which could lead to nutrient deficiency in some populations, the AR to the amount representing the average nutrient requirement for a defined group and the RI to the amount of nutrients believed to maintain a good nutritional status among practically all healthy individuals. The percentage of a population that has an intake below the AR indicates the proportion at increased risk of inadequate intake, i.e. if intake levels correspond to the AR, the risk of inadequacy is 50%. A safety margin of usually two standard deviations is added to RI in order to account for individual variations (NCM, 2004).

3 Methodology

3.1 Interdisciplinary research

In this thesis an interdisciplinary research approach has been used to study the sustainability of current and future food systems from the perspectives of the environment and health.

The traditional approach for analyzing complex systems is by breaking down the system into smaller research topics that are studied in detail within different disciplines. As environmental and societal problems in practice often cut across the borders of many disciplines, the need for bridge-building between different, interrelated disciplines has become increasingly acknowledged.

In the literature there are various ways of describing interdisciplinary research (Aboelela et al., 2007). A definition that is well consistent with the approach used in this thesis is that presented by the National Academy of Sciences (2005):

> *"Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice."*

Depending on the level of integration, a distinction can be made between multidisciplinary, interdisciplinary and trans-disciplinary research. In multidisciplinary research the same issue or problem is studied by different disciplines which work in parallel without integrating methods and knowledge. Interdisciplinary research brings together insights produced from different perspectives and disciplines to enable an integrated analysis of a research topic. At an even higher level of integration, trans-disciplinary research is a problem-based approach which combines knowledge, theories and methods that span over several disciplines within both the academic and non-academic sector (Frodeman et al., 2010).

Traditionally, environmental and health aspects of food and diets have been treated as two separate fields. In order to identify and take into account interactions and synergies, the fields have been increasingly integrated in both the research and policy area. The research approach in this thesis ranges from interdisciplinary to trans-disciplinary. To meet the research objectives (1.2), methods originating from the field of environmental system analysis (e.g. life cycle assessment and scenario analysis) are integrated with methods and data from the field of nutrition and health (e.g. nutrient calculation, nutrient requirements and consumption and production data). A more detailed description of the methodological approach used in paper I and II is found in paragraph 3.6.

3.2 Life cycle assessment

Life cycle assessment (LCA) is a methodological framework for calculating the environmental impact of a product, process or service for all stages throughout its life cycle (ISO, 2006a, ISO, 2006b). In 1969 Coca Cola was among the first to use the life cycle concept to explore the resource and environmental profiles of different packaging materials for their products (Hunt, 1974). In the 1980´s a framework for LCA was developed by the Society for Environmental Toxicology and Chemistry (SETAC) and in 1997 the methodology was standardized by the International Organization of Standardization (ISO) (Huppes, 2012).

The life cycle concept implicates a holistic approach by which the whole system is included in the assessment rather than individual parts being studied separately. Life cycle assessment can be used to explore the environmental improvement potential of products and processes, in decision making, for example for strategic planning and prioritizing in the industry, for marketing, such as eco-labeling of products, and to compare the environmental impact of different products or processes with similar functions (ISO, 2006a). A distinction is made between accounting, also called attributional LCA, and consequential LCA. An accounting LCA aims to quantify the environmental impact of a specific product or process from a known system, whereas a consequential LCA evaluates the consequences of decisions on changes in a system (Baumann, 2004).

According to the ISO standards 14040 and 14044 (ISO, 2006a, ISO, 2006b) a LCA consists of four steps (Fig IV). The first step is the *goal and scope definition* which describes the purpose of the study and for what purpose the results are to be used. The object and system to be studied are specified by defining the functional unit and system boundaries. In step two, the *life cycle inventory* (LCI) *analysis,* data are collected to quantify the amount of resources used and emissions produced in activities within the system studied. The environmental impact of the system studied is evaluated in step three, the *life cycle impact assessment* (LCIA), by first classifying the LCI data into different impact categories (classification) and thereafter calculating the relative contribution to each type of environmental impact, meaning that emissions affecting the climate, for example, will be converted to CO_2 eqs. (characterization). Step four is the *interpretation phase* which aims to analyze the results, evaluate limitations of the study, draw conclusions and make recommendations. In this step uncertainty and sensitivity analyzes can be performed to assess the uncertainty in the input data and the reliability of the results.

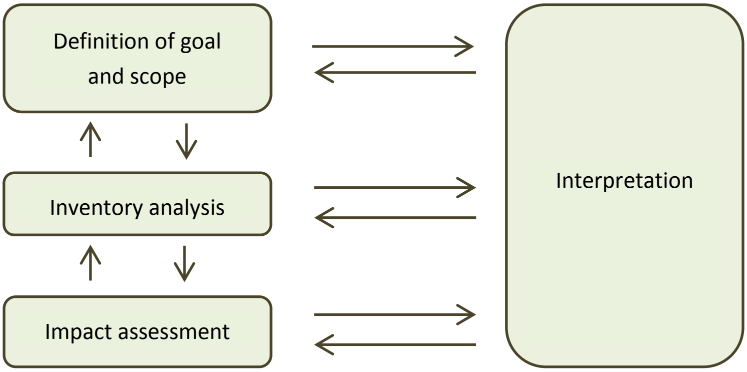

Figure IV. Steps included in life cycle assessment, adapted from ISO (2006b)

Parameters of particular importance in the LCA methodology are the functional unit, the system boundaries and the allocation procedure. The *functional unit* is the reference base to which input and output flows can be related. It describes the function of the object studied and enables comparison between different systems (ISO, 2006b). In LCAs of food it is common that the environmental impact is expressed in relation to a functional unit based on the quantity or volume consumed or produced (Schau and Fet, 2008), for example per kilogram, liter, serving portion or meal. The functional unit can also be based on the economic value of the food (e.g. profit or price) or demand for resources (e.g. land area). In order to account for the quality of food it has become increasingly common to use functional units which relate to the nutritional content, for example to the energy or protein content or the recommended daily intake of nutrients (Schau and Fet, 2008).

The *system boundaries* specify which processes are included or excluded in the assessment. Boundaries can also be set against the life cycles of other products and to define the natural system as well as the geographical and temporal coverage of the study (ISO, 2006b). Ideally, LCAs should include all phases of the life cycle of the product, from the cradle to the grave. In the case of food this means that all activities from the primary production of raw materials to the waste handling are accounted for. In practice, it is common to exclude activities deemed to have a negligible impact on the results. Many LCAs on foods include only activities up to the farm gate, since, in general, the agricultural production is responsible for the largest share of the total environmental impact of food products (Schau and Fet, 2008, Sonesson et al., 2010).

Allocation is applied if a system generates more than one product. In the dairy sector, for example, the environmental impact must be allocated between the production of milk and meat. If possible, allocation should be avoided by system expansions, meaning that by-products are assumed to substitute equivalent products whose environmental impact is subtracted from the overall environmental impact of the system studied. If system expansion is not applicable, allocation is normally based on physical properties, e.g. energy content, weight and volume, or economic value (ISO, 2006b). When comparing different products it is important that the choice of functional unit, system boundaries and allocation procedure are comparable.

In the research field of the environmental impact of food, LCA has evolved from primarily being used to analyze separate foods to quantify the impact of complete meals and diets. In several studies, the environmental impact of food is quantified for an entire nation or region by combining LCA food data with production and/or consumption statistics for the given population (Berners-Lee et al., 2012, Tukker et al., 2011, Wallen et al., 2004).

3.3 Nutrient Calculation

To calculate the intake of nutrients in the diet of a population or a person, information is required about the quantity and type of food consumed as well as about the nutritional content of the food consumed. In the past, nutrient calculation was a difficult and time-consuming method, which was performed by looking up the nutrient content of each food in a book or list, multiplying the nutrient content by the quantity of the food consumed and manually documenting the results. Today, nutrient calculation is in general performed by using computerized food consumption databases and software (Willet W., 2013).

Food	Intake (g)
Yoghurt, fat 3%	200
Banana	105
Whole grain muesli	40

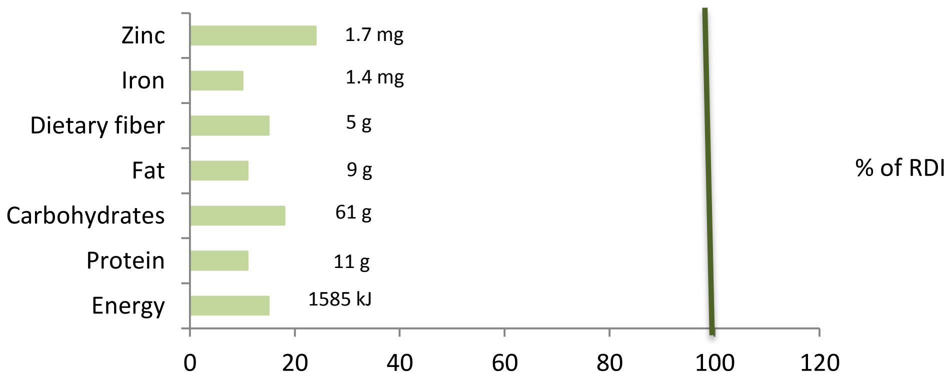

Figure V. Schematic illustration of the procedure of nutrient calculation. Nutrient intake from food intake is evaluated against the level of recommended daily nutrient intake (RDI).

Nutrient calculation makes it possible to calculate the nutritional content of different diets and relate them to nutrient requirements and recommendations. It is an important tool used, for example, by nutritionists to develop nutritional and dietary recommendations, by dietitians to counsel patients in dietary changes, by researchers and epidemiologists to correlate food components with causes or prevention of diseases and by food service managers to plan healthy menus for the public sector (Schakel et al., 1997).

The nutrient content of food in nutrient databases is either based on chemical analysis or estimated values. Estimated values of nutrient content are used because the chemical analyzes are often too costly, especially for foods that are rarely consumed or for nutrients insignificant. There are various procedures to estimate the nutrient content of food. For example, the estimated values can be based on the nutrient content of other components from the same food (e.g. chicken wings and chicken breast), on the nutrient content of similar foods (e.g. peach and nectarine), on defined algorithms (e.g. energy from protein, fat and carbohydrates = total energy content) or conversion factors (e.g. retention factors for nutrient losses during cooking). In some cases the nutrient content in a special food is estimated to be zero, for example, for the case of cholesterol and vitamin B_{12} in plant-based foods or dietary fiber in animal products. The nutrient content of foods containing several components can be calculated by summing the nutrients of all ingredients (Schakel et al., 1997).

In sustainability assessments of diets nutrient calculation can be used to design the dietary scenarios to be studied, to choose an appropriate functional unit for the system to be studied or to quantify the effect on nutrient intake of dietary change. To increase the comparability of the dietary scenarios, it is, for example, common that the energy and/or protein content are standardized for all dietary scenarios analyzed or that all dietary scenarios are required to meet specific nutritional recommendations. In order to account for the function, LCAs of food and diets can choose a functional unit related to the content of a specific nutrient or to an index which reflects the content of several nutrients. Nutrient calculation can also be used to evaluate the effects of dietary change on nutritional status and health by comparing the quantified nutrient intake from different dietary scenarios with nutrient recommendations and requirements for different groups of the population.

3.4 Scenario analysis

The use of scenarios to study a possible future course of events and consequences of strategic decisions dates back to the fifties when Herman Kahn at Rand Corporation introduced the method for use in military planning (Kahn, 1967). Since then, scenario analysis have been used for a wide range of purposes in both the private and public sector, not least as a common and useful tool in environmental science and policy (Rothman, 2008). The GHG emission scenarios (SRES) set up by the IPCC (IPCC, 1990) and world energy outlooks published by the International Energy Agency (IEA, 2013) are examples illustrating how scenarios are used in the context of sustainability.

There are different definitions of the meaning of scenarios. According to the IPCC, scenarios can be described as "*images of the future, or alternative futures that are neither predictions nor forecasts*" (Nakicenovic, 2000). The definition of scenarios by the United Nations Environmental Programme (UNEP) is "*descriptions of journeys to possible futures. They reflect different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play*" (UNEP, 2002). Scenario analysis is further described as the process of developing scenarios, comparing their results and evaluating their consequences (Alcamo, 2009).

There are also different approaches for performing scenarios analysis. Scenarios can be quantitative or qualitative, simple or of very complex character to be analyzed in computer models (Glenn, 2003). A distinction can also be made between exploratory (forecast) scenarios and anticipatory scenarios. Exploratory scenarios, also called descriptive scenarios, start in the present and explore possible developments in the future based on a set of assumptions. These types of scenarios typically answer the question "what if…?" and are used to explore the consequences of future trends or measures. Anticipatory scenarios, also called prescriptive or normative scenarios, are instead premised on a predetermined future vision and simulate what it takes to get there. These types of scenarios answer the question "how could…?" and can, for example, be used to develop a strategy for how to reach environmental goals (Alcamo, 2009, Swart, 2004).

Although no standard procedure exists for scenario analysis, four steps are typically included in the method. Step one clarifies the purpose and structure of the scenario analysis by defining the scope, target, indicators and potential policies. Step two lays the foundation of the scenarios by identifying drivers, critical uncertainties and creating the scenario framework. In step three the scenarios are developed and analyzed and step four involves the communication and spreading of results (UNEP, 2013). A more thorough description of methods used in scenario analysis can be found in Alcamo (2009).

Scenario analysis is also used for studying the effects of consumption on nature and society, for example, to evaluate the environmental or health impact of different dietary patterns (Berners-Lee et al., 2012, Scarborough et al., 2012, Tukker et al., 2011). With this approach the scenarios typically represent different types of diets, varying in amount and content of food or production method or origin, etc. In order to evaluate the effect of the different scenarios the results are compared to a reference or baseline scenario often based on the current dietary patterns of the population being studied. The impact of different scenarios is assessed by combining food consumption or production data with environmental, economic or nutritional data (Risku-Norja, 2011).

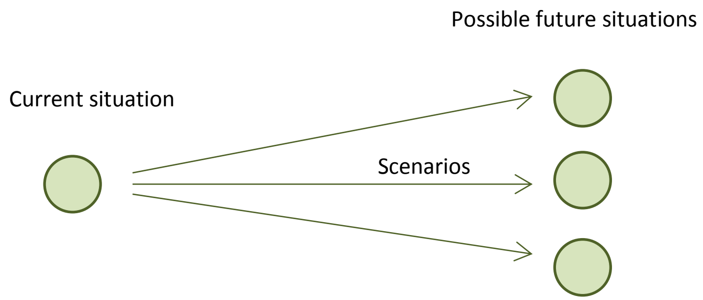

Figure VI. Schematic illustration of scenario analysis

3.5 Handling uncertainty

A key concern in the methodological approach of this thesis has been how to handle uncertainty in data, methodologies and results. Life cycle assessment, nutrient calculation and scenario analysis are methods used to describe and evaluate possible consequences of alternative actions. The methods include simplifications, assumptions and uncertainties that must be accounted for when interpreting the results. In this thesis uncertainty in methods and results is handled by aiming for high transparency in the presentation of the data, methods and assumptions used and by incorporating the estimated uncertainty in the analysis and interpretation of the results.

3.5.1 Uncertainty in life cycle assessment

In the discussion of uncertainty, a distinction should be made between uncertainty and variability. Uncertainty arises due to an incomplete knowledge of the true value, whereas variability is caused by the heterogeneous nature of data. Uncertainty in LCA results can be reduced by improving the performance and thereby the accuracy and quality of the study. Variability is instead handled by improving the knowledge of variability in input parameters and their overall impact on the results (Björklund, 2002, Huijbregts, 2002).

Uncertainty in GHG data for food has been estimated to be ± 10-30% or more (Röös, 2013b). Uncertainty factors in LCA can broadly be categorized as uncertainties in data and uncertainties due to methodological choices. Data uncertainties can be due to the use of inaccurate or unrepresentative data or that data are unavailable or missing. Methodological choices that can affect reliability are for instance the choice of functional unit, system boundaries, allocation procedure and characterization method. Variability in results can also be due to geographical, temporal or technological variability in input data (Björklund, 2002, Huijbregts, 2002)

According to the ISO standard, the interpretation step of LCAs should include an evaluation of the completeness, sensitivity and compliance of the analysis (ISO, 2006b). The control of completeness assesses whether all information required to draw conclusions from the results is available and complete. Guidelines are also provided for how to address potential gaps in data. In the sensitivity analysis the reliability is evaluated by varying factors identified as having a large impact on the outcome of the assessment, e.g. choice of functional unit or system boundaries. The consistency in assumptions and quality of data should be evaluated for different processes/activities and between different production systems before multiple products or processes are compared.

Monte Carlo analysis is a statistical method commonly used as a tool to handle the variability in LCA (Rubinstein, 2007). With Monte Carlo analysis the variability in input data is illustrated by presenting the results as a distribution of possible outcomes, rather than a single value. The overall variability in results is simulated, based on a large number of random samples from the probability distributions of each input parameter.

3.5.2 Uncertainty in nutrient calculation

As previously stated, calculation of the nutrient intake from a diet requires information on how much and what type of food is included in the diet as well as data on the nutritional content of all reported food items. The quantity and type of food eaten can be obtained from data based on agricultural supply statistics, household-budget surveys or individual dietary surveys (see paper I) and data on the nutritional content of food is provided by nutrient databases and software (see section 3.3). Both types of data are associated with uncertainties and variability that affect their accuracy and reliability.

To examine or calculate food consumption in an accurate and reliable way is difficult and generally, the data produced suffer from large uncertainties. Sources of uncertainties related to different types of consumption data, and how these uncertainties can be minimized or handled is thoroughly analyzed in paper I. Uncertainties related to data of the nutrient content of food can broadly be categorized as uncertainties due to variability of nutrient content in food, the quality and completeness of nutrient databases and discrepancies in methods to produce and categorize nutrient data (Willet W., 2013).

Nutrient databases typically contain one value indicating the nutrient content for each food. In some cases, data are available for the nutrient content of both the raw and cooked food item, for different cuts of the meat or for different cooking methods. However, in reality there are many more parameters which can affect the nutrient content. The size, growing and harvesting conditions, feed composition (animal-based food), degree of maturity (plant-based food), procedure for processing, storage and cooking, are just a few of the reasons why the nutrient content of a food item may vary (Willet W., 2013). The nutrient intake may also depend on eating habits, for example, whether there is a preference for eating chicken with or without skin. Due to the variability, nutrient values in databases and software should be interpreted as mean values rather than precise values (SFA, 2013).

To ensure the quality and reliability of the data provided by nutrient databases regular updating, quality control and validation of data selection and calculation methods are required. Over time, improved technology and methods for nutrient analysis will become available and the composition of food will change. In addition, there are constantly new food products available on the market (Schakel, 2001, Schakel et al., 1997). The completeness of a nutrient database depends on the availability of both food items and nutrients. The food items included in the database should reflect the foods which are major contributors to nutrients in the population studied (Willet W., 2013). The number of nutrients covered depends on the aim of the nutrient calculation, but it is important to remember that a missing value will be treated as zero, which may affect the results of the calculation (Westrich et al., 1994).

In order to combine and compare the nutrient data of different foods and nutrients, methods to produce and categorize data should ideally be harmonized within and between different databases (SFA, 2013, Westrich et al., 1994). Because nutrient databases are developed for different purposes and with different economic and time budgets, and due to the fact that all foods and nutrients cannot be analyzed by the same methods, this is unfortunately not the case. The lack of harmonization within and between databases adds to the overall uncertainty in the data for the nutritional content of food.

3.5.3 Uncertainty in scenario analysis

The future is uncertain and thus impossible to predict. As described earlier, the goal of scenario analysis is therefore not to make predictions, but rather to present alternative possible images of the future. In this way, scenario analysis in itself is a method used to handle uncertainties in the future.

In general, uncertainty is a bigger problem in long-term studies than in short-term studies. The reliability in long-term scenario analysis is dependent on the completeness and quality of input data, knowledge of the system and the drivers of change and the occurrence of unexpected events and novel behavior (Reilly and Willenbockel, 2010). However, due to the uncertainty in food consumption statistics (paper I) and in data for the environmental impact of food, there can be large uncertainties also in short-term scenario analysis.

To identify, characterize and reduce uncertainty in scenario analysis it is suggested that uncertainty assessment is carried out at all stages throughout the analysis (Refsgaard et al., 2007). Uncertainty assessment can be done by various methods. To present the results of the scenario analysis with uncertainty intervals rather than as precise values can facilitate the evaluation of the reliability of results. Uncertainty can also be managed by performing multiple scenarios representing different input data and assumptions and by sensitivity analysis where uncertain input data are varied while all other inputs are held constant. As shown in Figure VI, the different scenarios in this way provide a range of possible outcomes which illustrate the inherent uncertainty of the analysis.

3.6 Methodological approach in paper I and II

3.6.1 The method used in paper I

In order to study uncertainties in the production and use of meat consumption data and their potential consequences, a systematic analysis of the *reliability, discrepancy and transparency of meat consumption statistics* is performed in paper I.

The analysis is based on a literature review of data and information derived from scientific articles, statistical reports, online databases, as well as personal communication with authorities in the field. The information on meat consumption statistics collected is categorized and analyzed based on the methods used to produce meat consumption data, how consumption of meat is defined in different types of data and how statistical sources at a national, regional and international level produce and present meat consumption data.

The first part of the study analyzes the implications of using meat consumption statistics based on *agricultural supply, household-budget surveys or individual dietary surveys*. Here, the different methodological procedures and how these affect the quality of the generated data are described. Strengths and weaknesses of the respective methods are addressed as factors of importance for a correct use and interpretation of the data.

The second part of the study analyzes discrepancies and uncertainties in meat consumption statistics due to assumptions regarding *bone weight, food losses and waste, weight losses during cooking and non-meat ingredients*. Procedures for handling these uncertainty factors depending on the context and method used to produce meat consumption statistics are described. To illustrate the possible implications of discrepancies for subsequent use of data the individual impact of the uncertainty factors is estimated on the basis of information derived from the literature review.

The procedure of producing and presenting meat consumption data in *Swedish statistics, Eurostat and FAOSTAT* (EC, 2010, FAO STAT, 2011, SBA, 2011) is described in the third part of this study. Transparency and discrepancy in how data are produced and what they refer to in the statistics at the different levels is evaluated, with special emphasis on the uncertainty factors identified in part two.

The consequences of variability in the data for a correct choice of input data, functional unit and system boundaries in the application of LCA and nutrient calculation are illustrated by quantitative examples of the environmental and health impact of meat consumption.

3.6.2 The method used in paper II

In paper two the impact of changes in meat consumption on the dietary contribution of nutrients, GHG emissions and on land requirement is analyzed by the use of exploratory, quantitative scenario analysis. Uncertainty and variability in nutrient content, GHG emissions and land use are captured by using Monte Carlo simulation.

The scenarios analyzed represent three different variants of meat consumption in Sweden. The reference scenario (REF) refers to the current per capita meat consumption in Sweden (2009) (SBA, 2011), while NUTR-1 and NUTR-2 are hypothetical scenarios in which the amount and type of meat correspond to Swedish and international dietary recommendations for healthy meat intake (Enghardt Barbieri, 2003, WCRF/AICR, 2007). In NUTR-2 the type of meat consumed is, in addition, adjusted to optimize land use efficiency.

The contribution of nutrients from meat consumption is quantified for energy, protein, total fat, saturated fat, iron and zinc. Meat consumption in the scenarios is allocated to either consumption of beef, pork, chicken, mixed charcuteries and unmixed charcuteries, based on the above criteria. Trade data on the average sale of meat in Sweden (SFA, 2012, SPMA, 2012) are further used to divide the consumption among 37 different meat products with varying nutrient content. The nutrient content is quantified by combining the amount of each meat product consumed with the respective nutrient content based on data (uncooked weight) from the Swedish Food Agency´s food data base. The results are presented as the average contribution of nutrients per capita and day and are evaluated in relation to the mean recommended daily intake of nutrients for adults (NCM, 2004).

Based on previous LCA data the environmental impact of the production of meat consumed in Sweden is quantified with respect to GHG emissions and land demand and reported per bone-free weight at the farm gate. The scenarios represent conditions in a near-time perspective, meaning that the production systems correspond to today´s performance without any assumptions on technical development. The amount of bone-free meat produced is calculated based on national statistics on average meat consumption. The categorization of origin and production system of the beef, pork and chicken consumed in Sweden is based on a literature review of trade and agricultural data.

The climate impact of domestic meat production is calculated based on data from a study which describes GHG emissions of Swedish meat production in 2005 with a life cycle perspective up to the farm gate (Cederberg, 2009). Average values of GHG emissions for pork and chicken described in Cederberg et al. (2009) are used as averages in this study, while for beef new values are specified for five different production systems. An uncertainty range for GHG emissions in meat production is established based on an uncertainty-importance analysis where realistic, minimum and maximum values are set for parameters with the greatest influence. Greenhouse gas emissions for imported meat are approximated to the Swedish production systems. The results are presented as the average emissions of GHGs per capita per year and are evaluated in relation to a theoretically sustainable level of total GHG emissions, here set to 1.5 tons of CO_2 eq. per capita per year (EC, 2006, UNEP, 2010).

Land use for meat production is reported as the total area demand for feed production, including both cropland and pasture land. The area is calculated by dividing the amount of feed needed per kg of meat in different production systems by the yield per hectar for different types of feed. The results are presented as the average land demand per capita per year and are evaluated in relation to a theoretical limit for sustainable expansion of global cropland (Rockstrom et al., 2009) here set 0.22 ha per capita.

4 Results and Discussion

4.1 Paper I

4.1.1 Differences in statistical methods and definitions

Three main methodological approaches exist to produce consumption statistics. Consumption data can either be derived from statistics of agricultural supply, household budget surveys, or individual dietary surveys. Being aware of the method used to produce consumption statistics is important because the definition of consumption varies, which has consequences for how the data should be interpreted and used in an appropriate manner.

Meat consumption statistics based on the agricultural available supply describes the average quantity of meat available for human consumption within a country. This type of data is useful to study consumption trends over time and for comparing consumption in different countries. As the data refer to the average consumption for the whole population and as household waste is not accounted for it is not suitable for studying consumption characteristics in different socioeconomic groups or individuals or to describe what people actually eat. Factors that are important to consider in the use of meat consumption data based on agricultural available supply includes how the consumption of non-commercial meat, meat in processed and prepared meals as well as food losses and waste are accounted for.

Meat consumption statistics based on household budget surveys provide information on the amount of money spent on meat per household and sometimes also on the quantity of meat purchased per household. The data can be used to study and compare consumption in different regions and socioeconomic groups. As the data do not describe what happens to the meat after purchase they are more suitable for studying meat consumption in populations than in individuals. The procedure for categorizing different types of meat, accounting for food waste and for food consumed outside the household are factors that may affect the reported amount of meat purchased.

Individual dietary surveys provide data which refer to the actual amount of meat eaten by individuals and groups and is thus the most accurate method for obtaining data on food consumption. These data offer the possibility to study dietary habits and their consequences at an individual level, and to match dietary habits to different characteristics within the population. When data based on individual dietary surveys are presented and used, it should be clear whether they refer to raw or cooked meat, and whether household waste is accounted for.

4.1.2 Main uncertainty factors

Depending on the methodology used to produce meat consumption statistics the data may refer to the available supply, the purchased, the consumed or the eaten amount of meat. In order to facilitate a correct interpretation and use of meat consumption data, four main uncertainty factors to be considered are identified.

Bone weight
Depending on whether meat consumption statistics are presented as with or without bones the data may vary by about ±25-40%. Consumption statistics based on agricultural supply often, but not always, refer to meat including bone weight, whereas data based on household budget surveys and individual dietary food surveys refer to the amount of meat purchased at retail and/or the amount actually eaten, indicative to bone-free meat.

Food losses and waste
Whether losses and wastage in the different stages of the supply chain are accounted for or not may affect meat consumption data by +/- 15-20%. Meat consumption data based on agricultural available supply do not account for household wastage, whereas post-farm losses up to retail may be included. Meat consumption data based on household budget surveys and individual dietary surveys rarely or only partially account for food waste in the household.

Raw or cooked weight
Meat consumption statistics can be presented either as raw or cooked weight. Depending on how the data are presented the reported amount of meat consumed may vary by +/- 20-50%. Meat consumption data based on agricultural available supply and household budget surveys in general refer to raw weight, whereas data based on individual dietary survey as well as nutritional recommendations can be reported either as raw or cooked weight, depending on the method used.

Mixed meat products and prepared meals
Meat consumption statistics may vary by about +/- 40-55 % depending on whether the data refer to the total weight or only the meat content in mixed meat products and prepared meals. Meat consumption data based on agricultural data often but not always refer to only the meat content of such products whereas data based on household budget surveys and individual dietary surveys in general refer to the total weight including non-meat components.

4.1.3 Need for transparency

The review of meat consumption statistics provided by Sweden, Eurostat and FAOSTAT show a lack of accessible and transparent descriptions of underlying assumptions and procedures used to generate meat consumption data. Information on assumptions regarding bone weight, food losses and meat content in mixed and prepared meals is in particular difficult to find.

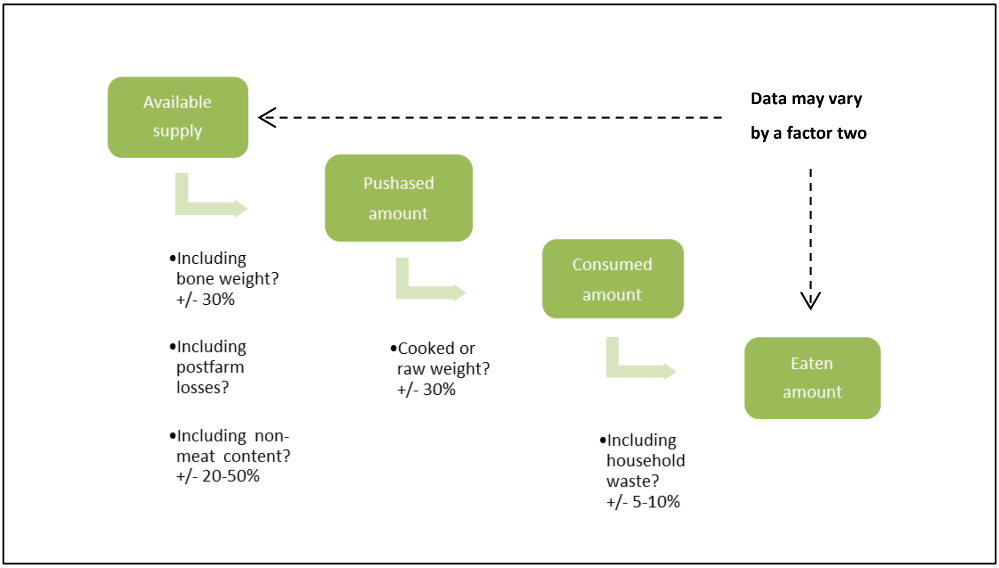

Figure VII. Schematic illustration of factors causing variability in meat consumption data

4.1.4 Implications of findings

Due to the use of different methodologies and definitions to produce and present consumption data, the meaning of one kg of meat can differ substantially. The problem is reflected by the divergent information in circulation in the literature and in the media on how much meat is eaten.

The findings of this paper demonstrate that per capita meat consumption levels can vary by a factor of two or more due to inconsistencies in the way statistics are produced and presented (Fig VII). In subsequent calculations of environmental and health effects of meat consumption (e.g. in LCA, nutrient calculation and scenario analysis) there is an obvious risk that consumption data are misinterpreted and used for the wrong purpose. An incomplete understanding of meat consumption data can thus have widespread implications for research findings and recommendations based on these.

This paper emphasizes the importance of being aware of what the data represent when meat consumption data are interpreted and used for further calculations. Meat consumption statistics based on the agricultural available supply of raw meat, including or excluding bones, are often the basis for environmental assessments of dietary patterns, whereas data on the actual intake of meat, expressed as uncooked or cooked meat, are generally employed to study the nutritional and health effects of diets. If consumption data are to be combined with data on the environmental impact or nutritional content expressed per kg of meat it is critical that the functional units correspond to each other. The uncertainty factors described in this paper can be used as a check list to evaluate the equivalence between the data.

A prerequisite to avoid misinterpretation of meat consumption statistics is that accessible and transparent information about the data is provided. Currently, descriptions of the methodology and assumptions used for producing consumption statistics are often inadequate or difficult to find and interpret. We believe that a more straightforward, complete and transparent documentation of consumption statistics would increase their usefulness and facilitate a proper use of the data.

4.2 Paper II

4.2.1 Meat consumption in the scenarios studied

Swedish per capita consumption of bone-less, uncooked meat in 2009 (REF) is estimated to be 170 g per day or 62 kg per year, of which almost one quarter is estimated to consist of charcuteries. Charcuteries consumed are estimated to consist to 62% of meat, of which most is pork (83%) and a smaller share is beef (17%). If the total weight of consumed charcuteries, including the non-meat content, is accounted for, per capita consumption of meat increases to 190 g per day or 70 kg per year. To meet Swedish and international guidelines for a healthy meat intake (NUTR-1, NUTR-2) the current consumption of pure, uncooked meat is reduced by approximately 25%, to 125 g per capita and day, and intake of charcuteries by 100%. The proportions of beef, pork and chicken in NUTR-1 and NUTR-2 are 24%, 24% and 52% and 10%, 0% and 90%, respectively.

4.2.2 Effect on nutritional contribution

The reduction in meat consumption required to meet guidelines for a healthy meat intake (NUTR-1, NUTR-2) reduces the contribution of total and saturated fat by about two thirds, of energy, iron and zinc by about half and of protein by about a quarter, in comparison with current meat consumption (REF). For most nutrients uncertainty intervals are in the range of +/- 50% but for some they are even larger. Current Swedish meat consumption (REF) contributes about 14% of the recommended daily energy requirement, about one third of the maximum RDI of total fat and saturated fat and between approximately one and two thirds of the RDI of protein, iron and zinc. In NUTR-1 and NUTR-2 the contribution of energy, protein and iron is, on average, equivalent to 7%, 40% and 14% of the RDI, respectively. The corresponding contribution of total fat, saturated fat and zinc is between 8-11%, 8-14% and 29-38% of RDI, respectively (Fig VIII).

4.2.3 Effect on greenhouse gas emissions

The production of meat currently consumed in Sweden (REF) emits about 0.6 tons of CO_2 eq. per capita and year, representing approximately 40% of the total budget for sustainable GHG emissions. A dietary change towards healthier meat consumption would reduce the GHG emissions to approximately 0.4 and 0.2 tons of CO_2eq. per capita per year in NUTR-1 and NUTR-2, respectively. Meat consumption would in these scenarios account for some 15-25% of the GHG emission budget (Fig VIII). Uncertainty intervals for GHG emissions in the scenarios studied range from approximately -15% to + 85%.

4.2.4 Effect on land use requirement

Meat production in REF demands 0.11 ha per capita per year, representing half of the theoretically available cropland in 2050. A dietary change towards healthier meat consumption would reduce the demand for agricultural land to 0.07 and 0.04 ha per capita per year in NUTR-1 and NUTR-2, respectively. This would reduce the share of global, available cropland for meat production per capita to about 20-30% (Fig VIII). The uncertainty intervals for land requirement in the scenarios studied range approximately from -25 to +110%.

4.2.5 Implications of the findings

The results on nutritional contribution indicate that a 25% reduction in current Swedish meat consumption would have a minor effect on nutritional status concerning energy and protein intake, whereas the intake of total fat, saturated fat, iron and zinc is reduced more strongly. The decrease of saturated fat in NUTR-1 and NUTR-2 corresponds to a 20-25% reduction of total saturated fat in the Swedish average diet. The reduction is assumed to bring positive health effects in the majority of the population as average intake levels in Sweden are higher than recommended (Amcoff, 2012) and is associated with increased risk of cardiovascular disease (WHO/FAO, 2003). The need to replace nutrient losses from a reduced intake of meat depends on the nutritional status of the individual as well as the amount and content of the rest of the diet. The need to replace nutrient losses in NUTR-1 and NUTR-2 by an increased intake of other foods appears to be greater for (fertile) women than for men and to be most critical in the case of iron. When interpreting the results it should be considered that meat consumption in the scenarios refers to per capita consumption, which may hide large variations between different groups in the population

A dietary change towards healthier meat consumption (NUTR-1, NUTR-2) would, according to the results, reduce per capita GHG emissions from meat by about half, compared to current meat consumption (REF). The change in diet would reduce the per capita emissions of Swedish food consumption and private consumption by about 10-20% and 3-5%, respectively. However, despite the lower climate impact in NUTR-1 and NUTR-2, meat consumption in these scenarios accounts for some 10-25% of the required emission target, which also needs to cover emissions from other foods and other activities such as housing, transportation and other consumption. To achieve sustainable levels of GHG emissions would thus require either more drastic changes in the diet, in combination with improved production systems, or that other sectors need to bear a greater share of emission reduction.

The availability globally of agricultural land may not be as critical but is largely dependent on agricultural intensity, soil fertility, changing climatic conditions and on future demand for agricultural products for purposes other than food. Current Swedish meat consumption (REF) occupies an area representing half of the area estimated to be available for sustainable cropping per capita, in 2050. In NUTR-1 and NUTR-2 the proportion of this area used for meat production is reduced to about 20-35%, which releases land that could be used for production of other types of food or for the production of for example bioenergy. The proportion of available cropland taken up for feed production in the different scenarios is somewhat overestimated, as part of the agricultural land used consists of grazing land. A transition towards more pasture-based beef production could reduce the competition for cropland but would instead result in a larger absolute requirement of agricultural land. An increased consumption of meat coming from monogastric animals (i.e. pork and chicken), as in NUTR-2, would instead further increase the pressure on cropland for feed production (e.g. soy). Such a development could be a driving force for increased deforestation in some areas and competes for cropland for direct human consumption.

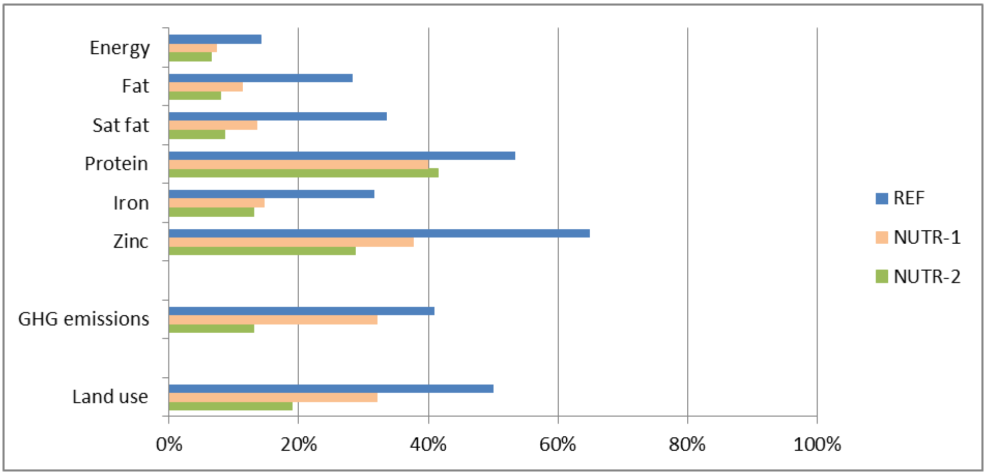

Figure VIII. Effect on nutrient contribution, GHG emissions and land use from changes in meat consumption, expressed in relation to nutritional recommendations (% of RDI), international climate goals (% of 1.5 tons of CO_2 eq./year) and theoretical capacity for sustainable expansion of global cropland (% of 0.22 ha/year).

5 Zooming out – The larger picture

5.1 Potential of dietary change

Since different studies use different methods and assumptions for assessing the sustainability, e.g. environmental and health effects, of food habits, the results may differ. To understand which measures can contribute to better eating habits and estimate the potential for increasing sustainability by dietary change thus requires that the results of several studies are analyzed and weighed up. In this chapter the effect of dietary change on climate, land use and health will be discussed based on the findings of a literature review of dietary scenario studies published between 2005 and 2013. The results of the studies are summarized in Table I. Additional information on the articles included in the review is found in Appendix.

Table I. Summary of results from review of dietary scenario studies

SCENARIO	GHG emissions (%)[1]	Land use demand[2]
Vegan diet	-55 to -25% (n=5)	-50% (n=2)
Vegetarian diet	-25 to -20% (n=5)	-50 to -5% (n=3)
Meat partially replaced by plant-based food	-20 to +5% (n=3)	-40 to -5% (n=5)
Meat partially replaced by dairy products	-5 to 0% (n=2)	-
Ruminant meat replaced by pork or poultry	-35 to -10% (n=2)	-40% (n=1)
Meat partially replaced by mixed food	-5% (n=2)	-
Balancing energy intake and expenditure	-10 to 0% (n=2)	-
Healthy diet	-35 to 0% (n=16)	-20 to +10 (n=5)

n= number of scenarios. [1]Effect of dietary change on GHG emissions from the diet, in % of GHG emissions of current average diet. [2]Effect of dietary change on demand of land, in % of total demand of agricultural land of the average diet.

5.1.1 Effect on climate

The literature review of scenario studies investigating the effect of dietary change on GHG emissions from a LCA perspective resulted in 10 articles covering 38 different dietary scenarios (Fig. IX). The majority of the studies focus on the effect of reducing or changing the consumption of meat and animal-based foods. The dietary scenarios can be categorized into diets defined as healthy, mainly characterized by a reduced intake of meat and increased intake and fruit and vegetables, diets in which the energy intake equals the energy expenditure, diets in which the meat consumption is reduced or changed, vegetarian and vegan diets. The effect on GHG emissions of the diet is expressed in comparison to the average diet in the population studied. In all the articles, the populations studied are European with unrestricted diets. Additional information on the study design and scenarios used in the articles reviewed is found in Appendix, Table VI.

According to the results the most effective measures to reduce the climate impact of the diet is to avoid meat and animal-based products. Based on the results avoidance of all animal products (vegan diet) could reduce the climate impact of the average European diet by about 25-55% (n=5). Five scenarios showed that a transition to a vegetarian diet could reduce the GHG emissions by about 20-25%. To completely avoid all meat and animal products would not be accepted or beneficial to all in the population. Dietary scenarios in which the effect of partially replacing meat by other foods is analyzed are therefore also of great interest. A change towards healthier eating habits could, according to the results, reduce the climate impact of the diet by about 0-35% (n=16). In the majority of the healthy diet scenarios (n=11) the reduction potential is between 10-35% while five scenarios showed a smaller potential of zero to five percent. Also the scenarios in which meat consumption is reduced or changed show a potential to reduce the GHG emissions of the diet by 0-35%, depending on the amount and type of meat which is modified as well as the type of food which substitutes the meat. In one of the scenarios, in which meat is partially substituted by a self-selected vegetarian diet, GHG emissions increase by about 5%. Furthermore, two scenarios showed that balancing the energy intake and expenditure could reduce the GHG emissions by 0-10% depending on the physical activity level assumed.

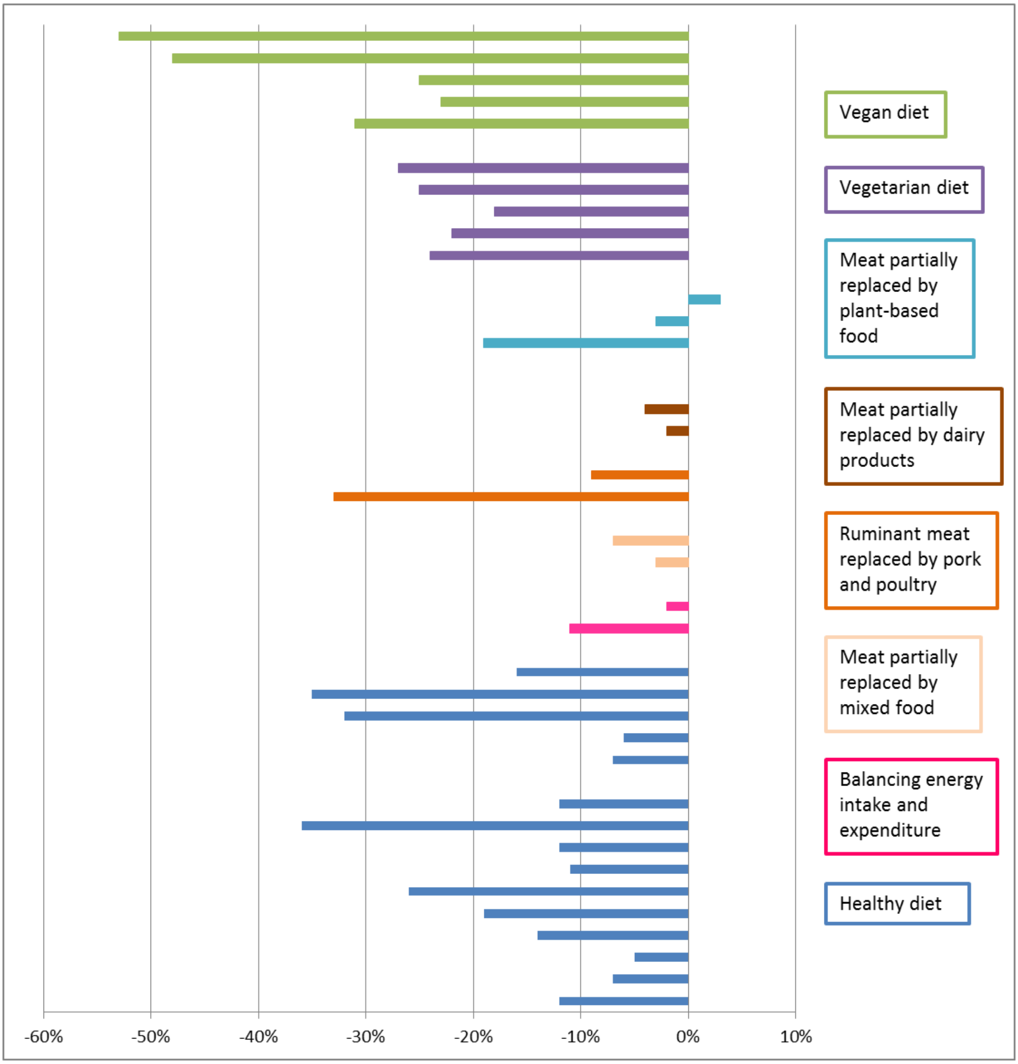

Figure IX. Estimated effect of dietary change on GHG emissions from the diet, in % of GHG emissions of the average diet in some European countries/regions with unrestricted diet. The data presented are based on results of 38 scenarios included in 10 articles. For references see Appendix, Table VI.

5.1.2 The effect on land use

The literature review found five articles, presenting 16 dietary scenarios, which analyzed the effect of dietary change on current demand for agricultural land (Fig. X). In addition, three articles, including nine dietary scenarios, with projections for 2030 and 2050 were found. Also in the scenario studies focusing on the diets′ demand for land, the majority of the scenarios analyzed the effect of changed consumption of meat and animal-based foods. In Figure X the effect of dietary change on per capita land use demand is illustrated, expressed in comparison to the average diet in the studied population which in all studies consists of European populations with unrestricted diets. The results of the long-term scenarios are summarized in Table II and are expressed in relation to reference scenarios based on global average diets according to FAO projections. Additional information on the study designs and scenarios used in the reviewed articles is found in Appendix, Table VII.

According to the results the most effective measure to reduce the per capita land demand of the diet is partially, or completely, replacing the consumption of meat and animal-based products by plant-based foods. According to four studies, a shift to vegan or vegetarian diet could reduce the demand for agriculture land by about half and 25-50%, respectively. Another study estimated that an organic vegetarian diet could reduce the demand for agricultural land by about 5%. In the scenarios where meat is only partially replaced by plant-based food, limitation of the total meat consumption has the greatest potential to release agricultural land (-45% to - 15%, n=4). A clear difference in land demand can be noted between the consumption of ruminant and monogastric meat. One study estimated that replacing 75% of the ruminant meat by pork and poultry could reduce the land demand by 40%. Replacing half of the consumption of pork and poultry by plant-based food, however, would reduce the land demand by only 5%. Four of five studies showed that a healthy diet could reduce the demand for land by about 15-20%. A healthy diet based on organic production would instead increase the demand for land by about 10%.

Few of the studies found distinguish between different types of agricultural land. The studies which report the difference between cropland and pasture land indicate that reduced meat intake in particular has the potential to reduce the demand for pasture land. Only 5-10% (n=8) of the observed reductions in land demand consist of cropland, and to replace beef by pork and poultry may even increase the total demand for cropland. The results of the long-term scenario studies further indicate that both improvements in the production and changes in consumption will be needed to reduce future demand for agricultural land.

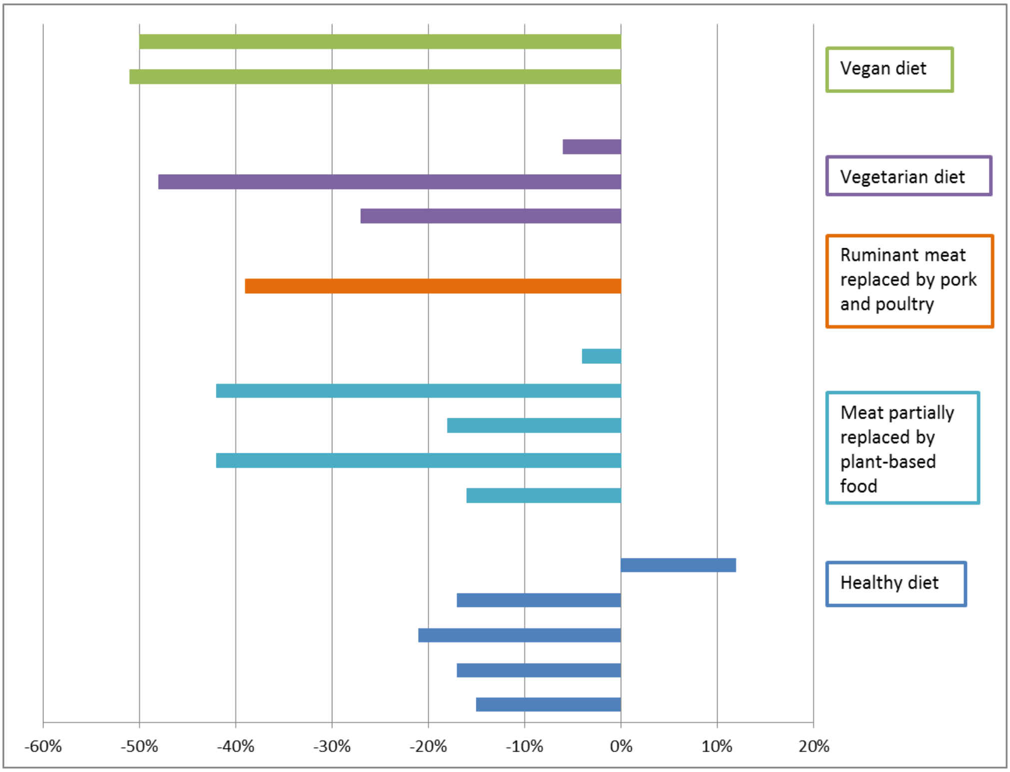

Figure X. Estimated effect of dietary change on demand for land, in % of total demand for agricultural land of the average diet in some European countries/regions with unrestricted diets. The data presented are based on results of 16 scenarios included in 5 articles. For references see Appendix, Table VII.

Table II. Effect on land use change of dietary change, summary of future scenario studies

		LAND USE CHANGE (Mha, (%))		
REFERENCES, DESCRIPTION	**SCENARIO**	**PASTURE LAND**	**ARABLE/ CROPLAND**	**TOTAL AGRICULTURAL LAND**
(Stehfest et al., 2009) Global, 2050	HEALTHY DIET	-1350 (-42%)	-150 (-9%)	-1500 (-30%)
	CHANGED MEAT CONSUMPTION			
(Powell and Lenton, 2012) Global, 2050	High meat consumption, low agricultural productivity			+3950 (+81%)
	High meat consumption, high agricultural productivity			-60 (-1%)
	Low meat consumption, high agricultural produtivity			-750 (-15%)
	Low meat consumption, low agricultural productivity			+2420 (+50%)
(Wirsenius et al., 2010) Global, 2030	Ruminant meat partially replaced by pork and poultry, increased agricultural productivity	-930 (-26%)	-60 (-3%)	-990 (-19%)
(Stehfest et al., 2009) Global, 2050	Ruminant meat replaced by plant-based food	-2700 (-84%)	-100 (-6%)	-2800 (-57%)
(Stehfest et al., 2009) Global, 2050	VEGETARIAN DIET	-2700 (-84%)	-150% (-9%)	-2850 (-58%)
(Stehfest et al., 2009) Global, 2050	VEGAN DIET	-3200 (-100%)	-150% (-9%)	-3350 (-68%)

5.1.3 The effect on health

To study the dietary effects on nutrition and health is a well-established area of research in medicine and public health. Within the area of sustainability, however, it is a relatively new concept to include nutrition and health aspects in studies of the sustainability of food. Therefore, there are only a few articles available in which both the environmental impact of the diet and its effect on nutrient intake or health have been analyzed. In the literature review four articles were found, including eight dietary scenarios, which quantified both environmental and nutritional and/or health effects of the diet (Table III). Seven of the scenarios study the effect of dietary change in European countries with unrestricted diets, whereas one scenario studies the effect of changed dietary habits in São Paulo. The effect on nutrient intake or risk of disease is expressed in comparison to reference scenarios based on the average diet in the populations studied.

The association between meat intake and increased risk of chronic diseases (e.g. coronary heart disease, stroke, diabetes type II and certain cancers) has been mainly linked to the consumption of red meat, processed meat, fatty meat and meat cooked at high temperatures (Ferguson, 2010, Micha et al., 2010). Increased intake of energy, cholesterol, fat, saturated fat and trans-fatty acids as well as carcinogens formed during the cooking or processing may partly explain the association between meat consumption and increased disease risk. Meat is, however, a good source of many minerals (iron, zinc and selenium) and vitamins (vitamin D, riboflavin, B_{12}) and contains all essential amino acids (Millward and Garnett, 2010, Wyness et al., 2011).

Based on the few studies in Table III, the greatest health gain comes from replacing red and processed meat by plant-based food, while scenarios in which either ruminant meat is replaced by pork, or poultry is replaced by plant-based food seem to have a negligible effect on health. To replace meat with plant-based food is also beneficial due to the relationship between consumption of fruit and vegetables and reduced prevalence of obesity, cardiovascular disease, cancer and overall mortality (Berkow and Barnard, 2006, Craig, 2010, Fraser, 2009, Li, 2011). Replacing red meat by plant-based foods may, however, reduce the intake of certain nutrients, e.g. of iron which is often inadequate in fertile women and whose bioavailability is lower in plant-based foods. More studies are needed to evaluate the amount and type of meat that should preferably be eaten from a health perspective, as well as what should replace the reduced intake of meat.

Table III. Effect on nutrition and health of dietary change

REFERENCES	SCENARIO	EFFECT ON NUTRITION/HEALTH
(Temme et al., 2013)	Ref: Average Dutch diet of young women in 2003	Average intake of iron 9.5[1] mg/d, average intake of saturated fat 13.2 E%
	30% of dairy and meat replaced by plant-based food	Average intake of iron 10.2 mg/d, average intake of saturated fat 12.1 E%
	100% of dairy and meat replaced by plant-based food	Average intake of iron 12.0[2] mg/d, average intake of saturated fat 9.2 E%
(Scarborough et al., 2012)	Ref: Average UK diet in 2005	
	50% of meat and dairy replaced by plant-based food	16% reduction of total deaths from CHD[3], stoke and diet-related cancers
	Ruminant meat partially replaced by pig and poultry	<1% reduction of total deaths from CHD[3], stroke and diet-related cancers
	Pork and poultry partially replaced by plant-based food	4% reduction of total deaths from CHD[3], stoke and diet-related cancers
(Aston et al., 2012)	Ref: Average UK diet in 2000/2001	
	Doubled proportion of vegetarians, reduced consumption of red and processed meat in remaining population[4]	6.4 - 9.7% reduced risk for CHD[3], 7.5-12.0% reduced risk for diabetes mellitus, and 7.7-12.2% reduced risk for colorectal cancer (women-men).
(Friel et al., 2009)	Ref: Average intake of saturated fat and cholesterol in UK based on dietary surveys from 1998, 2000 and 2003	
	30% reduction of saturated fat and cholesterol from livestock products replaced by polyunsaturated fats	15% reduced risk of ischaemic heart disease
(Friel et al., 2009)	Ref: Average intake of saturated fat and cholesterol in São Paulo based on a dietary survey from 2006	
	30% reduction of saturated fat and cholesterol from livestock products replaced by polyunsaturated fats	16% reduced risk for ischaemic heart disease

[1] Of which 10% was from haem iron, [2] Of which most was non-heam iron, [3]Coronary heart disease, [4]Consumption of red and processed meat adapted to the dietary pattern of the lowest fifth of the non-vegetarian population. Average intake of red and processed meat reduced from 91 to 52 g/d in men and 54 to 30 g/d in women.

5.2 How much meat can we eat to sustain a healthy life and planet?

5.2.1 The environmental and resource perspective

There are no general proposals on the share of the GHG budget (in this study assumed to be 1.5 tons CO_2 eq. per capita per year) that should be allocated to food-related or individual food items, e.g. meat, or how a sustainable distribution of global land resources, between crops for food and non-food uses and between crops for feed and direct human consumption, should be.

Due to the high share of emissions from biological processes in agriculture, the technical potential of reducing GHG emissions from the agricultural sector, and especially the livestock sector, is limited compared to many other sectors (EC, 2011, SEPA, 2012). The potential to reduce GHG emissions from meat production in the EU, through agricultural improvements, energy and resource efficiency throughout the supply chain, is for example estimated to be approximately 25% (Weidema et al., 2008). This means that GHG emissions from livestock production would remain substantial even if improvements in production were to be implemented successfully. To meet climate targets and simultaneously feed the world´s growing population thus requires dietary change towards food patterns with less climate impact or/and that other sectors, such as housing and transportation, need to bear a larger share of the global emission reduction.

From a resource and food security perspective the most efficient way to produce dietary energy and nutrients is generally to use the agricultural land to produce crops for direct human consumption. However, grazing on lands that are not suitable for farming and livestock production where the feed is based on waste products are resource efficient ways of producing animal-based food of high nutritional value. Grazing animals can also contribute to increased biodiversity by keeping landscapes open.

From a climate perspective an average global per capita consumption of 25-35 kg of meat per year (70-90 grams per day), of which not more than 18 kg per year (50 grams per day) from ruminants, has been suggested as a goal to maintain the current levels of livestock related GHG emissions until 2050 (Garnett, 2008; McMichael et al., 2007). The amounts refer to the average per capita available supply expressed in raw weight including bones, corresponding to approximately 15-25 kg/year (50-65 g/d) of bone-free meat or 10-15 kg/year (35-45g/d) of bone-free cooked meat. A sustainable consumption of meat can also be discussed based on the target of limiting GHG emissions to 1-2 tons of CO_2 eq. per capita (Röös, 2013c). The limitations in the technical potential of reducing GHG emissions from the agricultural sector could mean that a greater share of the emission budget should be allocated to the agricultural and food sector. Assuming that food consumption, for example, is allowed to account for halve of the total GHG emissions budget (0.5-1 t CO_2 eq./cap, year), of which meat is responsible for half of the emissions (0.25-0.5 t CO_2 eq./cap, year), per capita consumption would have to be limited to a maximum of 100-160 kg of raw, bone-free meat per year (290-430 g/d) if the consumption is based on only chicken and a maximum of 10-20 kg raw, bone-free meat per year (30-60 g/d) if the consumption is based on only meat from ruminants (Röös, 2013c).

From a resource perspective, similar calculations can be based on the world´s availability of cropland. Today, about a third of global croplands (about 500 Mha) are used for feed production (Hallström et al., 2011, Steinfeld et al., 2006). Based on average data on land demand for meat production (de Vries and de Boer, 2010, Hallström et al., 2013b), and a world population of nine billion in 2050 (UN, 2010), the area of cropland available for feed production will be about 550 m^2 per person in 2050, assuming that the current area of cropland for feed production has reached its maximum from a sustainability perspective. This land could provide approximately 15-55 kg of beef (excluding feed from pasture land) *or* 45-60 kg of pork *or* 55-70 kg of chicken per person (expressed in kg of raw, bone-free meat). Other ways to evaluate what is a sustainable consumption of meat from a resource perspective is to relate the production of animals to the national or regional availability of natural pasture lands, the consumption of dairy products or the amount of waste available to use for feed (Hallström et al., 2013b, Röös, 2013c).

5.2.2 The nutrition and health perspective

Moderate meat consumption in a well-balanced diet can be a good source of energy and nutrition. High intake levels of, particularly red meat, fatty and processed meat products is, however, associated with an increased risk of several common, non-communicable diseases (Ferguson, 2010, Micha et al., 2010, Miles, 2008, Sinha et al., 2009).

From a nutritional point of view there are no general recommendations of how much meat is considered to be optimal for health. Existing dietary guidelines are instead usually based on levels that ensure sufficient intake of critical nutrients without exceeding upper intake limits of nutrients associated with negative health effects. Because of this, the amount of meat that can be considered healthy depends to a large extent on the composition of the overall diet.

To decrease the risk of cancer the World Cancer Research Fund (WCRF) recommends that consumption of cooked red meat (e.g. beef, pork, lamb) should be restricted to a maximum of 500 g per week (25 kg/year, 70 g/d) on an individual level and to a maximum of 300 g per week (15 kg/year, i.e. 45 g/d) from a public health perspective. In addition, consumption of processed meat, such as bacon, salami, sausages etc., is recommended to be very limited or completely avoided (WCRF/AICR, 2007).

A healthy meat intake can also be estimated from the nutritional requirements, for example, of protein (Aiking, 2010). Based on WHO recommendations, the daily intake of protein should be 0.8 g per kg of body weight (WHO, 2002), equivalent to approximately 50-70g of protein per day. Assuming that one third of the protein is supplied by meat and that the content of protein in meat is 20%, the daily intake of meat for most people should be between 80-120 g of raw meat (e.g. 50-80 g of cooked meat).

To illustrate the quantities of foods which correspond to the nutritional recommendations, health organizations also provide food-based dietary guidelines. The proportions between different food groups (e.g. amount of meat) in such guidelines vary (Hallström et al., 2011) as they are often influenced by the typical dietary pattern in the country or region in question (Enghardt Barbieri, 2003), which in turn may be influenced by culture and religion. Table IV shows suggestions of healthy meat intake based on food-based dietary guidelines in different countries and parts of the world. The guidelines for meat intake vary from a completely vegetarian diet (e.g. India) (NIN, 2010), which can be supplemented with meat, up to an intake of 100 g of cooked meat per day.

Table IV. Food-based dietary guidelines on meat consumption

COUNTRY	RECOMMENDED DAILY MEAT INTAKE (cooked amounts, g/d)	SOURCE
Sweden	100[1]	Swedish Food Agency (Enghardt Barbieri, 2003)
China	50-100[2]	Chinese Nutrition Society (Ge, 2011)
USA	100[2]	U.S. Department of Agriculture, U.S. Department of Health and Human Services (2010)
Schweiz	70-85[1]	Swiss Society of Nutrition (Walter et al., 2007)
Germany	40-90	German Nutrition Society (2008)
Spain	60-100 g[1] lean meat per day + occasional intake of charcuterie and fatty meat	La Sociedad Española de Nutrición Comunitaria (2007)

Average meat per capita consumption in Sweden is estimated to be 110 g per day (Amcoff, 2012). [1]Weight reduction by cooking was assumed to be 30% of raw weight. [2]No information was given on whether the data refers to raw weight or cooked weight.

5.2.3 Current and future demand for meat

The global available supply of meat is approximately 280 Mtons, corresponding to an available per capita supply of 42 kg per year (raw meat including bones). In reality, meat consumption varies by a factor ten among people in different regions of the world (Fig XI). In North America per capita available supply of meat is 120 kg per year (320 g/d) while the average available supply in Africa is less than 20 kg per person per year (50 g/d) (FAOSTAT, 2013).

A high proportion of meat in the diet has a long tradition in many wealthy countries. In North America, for example, the per capita available supply of meat surpassed 100 kg per year already in 1970 (FAOSTAT, 2013). In many affluent countries, the rise in meat consumption has started to stagnate. However, in the last decades a strong trend of increasing production and consumption of livestock products has been seen in the developing countries, especially in East and Southeast Asia and Latin America (FAO, 2009).

Globally, the fastest growing sub-sector has been the poultry sector followed by the pork meat production, which since the 1960s increased tenfold and fivefold, respectively. During the same period the global production of ruminants approximately doubled. The increase in livestock production is the result of an increased number of animals and increasing yields. Technological development in the livestock sector has enabled increased output per animal, especially in poultry and egg production, as well as in the pork and dairy sector. In general the number of livestock increased faster than the yields during the past decades, meaning that the major increase in production can be attributed to a rise in the numbers of animals (FAO, 2009).

Projections indicate that the global demand for meat will continue to increase. FAO scenarios until 2050 estimate that global per capita consumption of meat will rise from about 40 kg at present to 52 kg in 2050 (Bruinsma, 2009). To meet such an increase in demand for meat, global meat production would need to increase by about 70% in the coming 35 years.

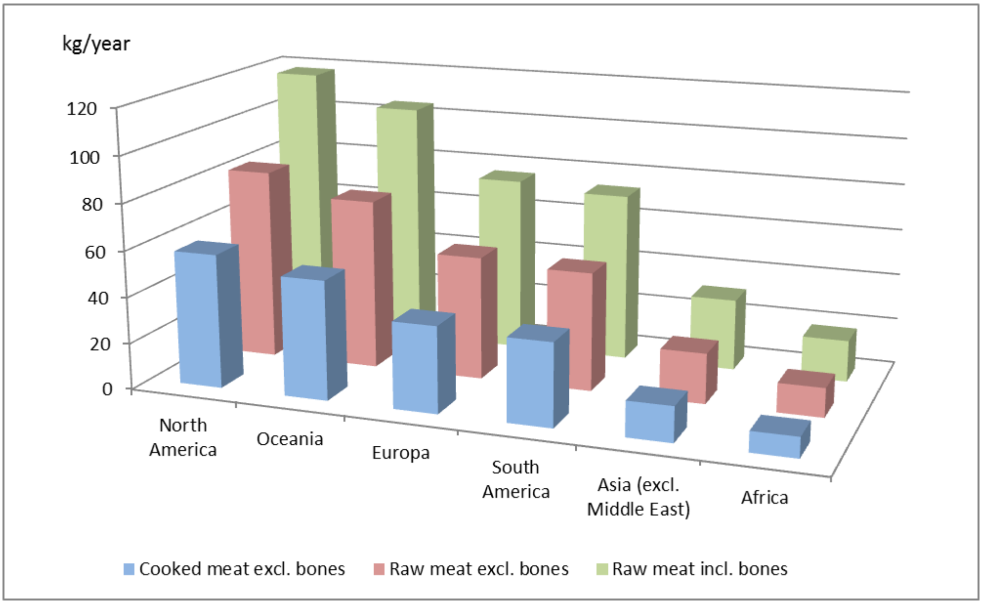

Figure XI. Per capita available supply of meat in 2009 (kg/year). Amounts of raw meat including bones are adapted from FAOSTAT (amounts without bones and after cooking are rough estimates based on the conversion factors in paper I).

5.2.4 Sustainable meat consumption

The evaluation of what can be considered sustainable meat consumption must include many different perspectives as it is a complex issue with multi-dimensional impact on the environment and society. Here, only three important aspects are considered.

From a health perspective it seems difficult to say how much meat is optimal. A healthy diet can contain more, less or no meat depending on the overall composition of the diet. However, based on the recommendations to prevent the risk of cancer the intake of cooked red meat should be less than 500 g per week (26 kg/year) per person and include none or only a small portion of processed meat. Based on the food-based dietary guidelines the total intake of cooked meat should further be limited to about 40-100 g per day (15-35 kg/year) in order to get enough nutrition from other food groups without having an excessive energy intake.

Also from a climate- and land-use perspective, the type of meat has a large impact on the sustainable levels of meat consumption. If the consumption is based on monogastric meat, a higher consumption is possible than if it is based on ruminant meat. To meet climate targets and avoid further expansion of global cropland, global per capita consumption may need to be limited to about 20-300 g/d (5-110 kg/year) and 30-130g (10-50 kg/year) of cooked meat per day, respectively, depending on the proportions of different types of meat (i.e. the ratio of poultry, pork and ruminant meat).

This interdisciplinary analysis with regard to nutrition, health, climate and land use (Table V) suggests that sustainable meat consumption, in perspective from the developed country/region, is characterized by a large proportion consisting of poultry, limited amounts of red and ruminant meat, avoidance of processed meat and a total meat intake which is in the range of 75 ± 55 grams of cooked meat per day (27± 20 kg per year)(excluding deductions for potential losses), depending on the type of meat included in the diet and the sustainability perspective considered. Further research is required to evaluate whether these preliminary results are consistent with sustainability criteria from other perspectives. Important aspects to consider are, among others, biodiversity, animal welfare and other social and ethical dimensions.

A rough comparison with current meat consumption levels in different parts of the world (Fig. XI) indicate that meat consumption in North America, Oceania, Europe and South America have reached a maximum or need to be reduced in order to be sustainable, whereas there is still a potential to increase the average consumption in Asia and Africa.

Table V. Suggested meat consumption levels from a climate-, land use- and health perspective

TYPE OF MEAT	SUGGESTED MEAT CONSUMPTION LEVEL				
	Kg/year		g/d		
	Raw, bone-free weight	Cooked weight	Raw, bone-free weight	Cooked weight	
					CLIMATE PERSPECTIVE
Ruminant meat	13	9	35	25	Current livestock-related emssions are maintained to 2050
Total meat	15-25	10-15	50-65	35-40	Current livestock-related emissions aer maintained to 2050
Only chicken	100-160	70-110	290-430	200-300	Climate targets[1] are met
Only ruminant meat	10-20	7-15	30-60	20-40	Climate targets[1] are met
					LAND USE PERSPECTIVE
Only chicken	55-70	40-50	150-190	105-130	No expansion of cropland for feed production to 2050
Only beef	15-55	10-30	50-150	30-105	No expansion of cropland for feed production to 2050
					HEALTH PERSPECTIVE
Red meat	< 35	< 25	< 100	< 70	Reduced cancer risk, induvidual level
Processed meat	0	0	0	0	Reduced cancer risk
Total meat	< 20-50	< 15-35	< 60-140	< 40-100	Nutritional requirements are met
Total meat	30-45	20-30	80-120	50-80	Protein requirements[2] are met

[1]Assuming meat consumption can be responsible for maximum 0.25-0.5 t CO_2 eq./cap, year. [2] Based on a protein requirement of 50-70g per day (0.8g protein/kg bodyweight), of which one third is supplied by meat. Protein content in meat is assumed to be 20%.

6 Future outlook

6.1 Alternatives to meat

A growing body of literature suggests that reduced meat consumption can offer multiple benefits, including reduced environmental impact and improved public health, in populations with unrestricted diets. However, the level to which meat consumption needs to be limited in order to be sustainable, and what should replace it, is still under discussion.

For individuals for whom a reduced meat intake entails a risk of an inadequate nutritional intake, the diet needs to be complemented by an increased intake of other foods. Products that can replace or supplement meat in the diet can be grouped as follows; plant-based meat substitutes (legumes, cereals, vegetables, nuts), processed vegetarian meat-substitutes (quorn, tofu, tzai, tempeh etc.), animal-based meat substitutes (white/lean meat, dairy, eggs, fish). In addition there are alternatives such as fortification and supplementation.

The majority of studies analyzing the sustainability of diet have so far been focusing on the effect of replacing parts of the meat consumption by plant-based foods. From a health perspective, increased intake of legumes, whole grain cereals, vegetables and nuts would be desirable in most populations with unrestricted diets (Srinivasan et al., 2006). A combination of these foods provides health promoting fibers, vitamins and antioxidants and nutrients to adequately meet the requirements, including all essential amino acids (Millward and Garnett, 2010, Van Duyn and Pivonka, 2000). However, due to the lower bioavailability of certain nutrients (e.g. iron and zinc), intake levels of plant-based foods may need to be substantially increased compared to current average intake, depending on the proportion of meat to be replaced.

To replace meat by plant-based foods has also been proven to be advantageous from an environmental perspective (Carlsson-Kanyama and Gonzalez, 2009, González et al., Reijnders and Soret, 2003). Legumes, cereals and vegetables, in many cases have 2-60 times lower climate impact and need 1-20 times less land per kg produced, compared to meat (de Vries and de Boer, 2010, González et al., Nijdam et al., 2012). There are, however, exceptions, for example diets which to a large extent include plant-based foods transported by air and/or produced in greenhouses with fossil heating which can be as climate intensive as meat-based diets (Carlsson-Kanyama, 1998, Jungbluth et al., 2000, Macdiarmid, 2013, Vieux et al., 2012).

As an alternative protein source, there is also a growing range of processed vegetarian meat substitutes available, typically based on protein from pulses, cereals or fungi (Asgar et al., 2010, Sadler, 2004). The environmental impact of processed vegetarian meat substitutes has so far been investigated only in a limited number of studies (Blonk et al., 2008, Davis et al., 2010, Finnagan, 2010a, Finnigan, 2010b, Leuenberger et al. 2010, Nijdam et al., 2012, Nonhebel and Raats, 2007, Xueqin and Ierland, 2004). The results indicate that these products require relatively more energy due to the higher degree of processing required, but have a lower climate and overall environmental impact, than most types of meat. The potential and limitations for increasing sustainability of a diet with consumption of this group of products requires further analysis. There is also a need for more interdisciplinary and holistic analyzes of other options to increase sustainability in the diet, such as replacing meat by different animal-based foods, e.g. healthier meat alternatives, fish, eggs or dairy products, or to include fortified foods or supplements in the diet to meet requirements of specific nutrients.

6.2 Differentiation on the individual, regional and social level

The general approach in dietary scenario analysis is to base the reference scenario on the average per capita consumption in the population studied. The diet registered in the reference scenarios is thereafter modified to examine the impact of different hypothetical dietary changes on the environment. Since consumption patterns and nutritional requirements differ depending, among other things, on gender, age and physical activity level, it would be of value to do more research on specific groups in the population.

In some studies, the reference scenarios are based on the consumption patterns of a particular group of the population. For example in the articles by Macdiarmid et al. (2012) and Temme et al. (2013) the reference scenarios are based on the food consumption of fertile women. This has the advantage that the nutritional content of the diet can be evaluated in the group of the population with the highest requirements of a potentially limited nutrient (e.g. iron). Men generally eat more meat and their diet has a higher environmental impact than women (Hallström and Börjesson, 2013a, Meier and Christen, 2012). Due to the higher consumption of meat and the lower requirements of iron, meat consumption could probably be reduced more in men´s diet than in women´s. This example shows that from an environmental, health and, not least, policy perspective it may be of interest to adapt dietary scenarios to specific groups of a population to a higher degree.

The review in paragraph 5.1 makes it clear that dietary scenario studies in general are designed to study the impact of dietary change in European countries/regions characterized by having an unrestricted diet. In many parts of the world trends of rapid changes in diet have had negative (and positive) implications from both health and environmental perspectives and this trend is predicted to continue as living conditions of more people improve. To understand the impact of dietary change in a broader perspective and not only to study how to implement change but how to prevent unhealthy and resource-intensive food habits, dietary scenario studies are increasingly required also in developing regions with different habits, cultures and conditions.

6.3 Optimization of land use

When discussing the availability of agricultural land it is necessary to distinguish between different types of land as this will affect the possibilities and consequences of how the land can be used and how its use can be optimized for food production.

As the major part of the current global food supply is dependent on cultivated land (Johansson, 2005) pressure on agricultural land is especially intense on cropland. However, as discussed previously dietary change, above all, has the capacity to release agricultural land currently used for pasture. Since all pasture land is not suitable for cultivation a distinction between different types of land is required for an improved understanding of the potential to reduce land use demand by dietary change. In the review in paragraph 5.1 such a distinction is made only in two out of five articles.

To avoid a situation in which demand for agricultural land is exported to other countries and regions where it might lead to deforestation and other negative impacts associated with increased land use pressure, it may also be of interest to distinguish between domestically produced food, and imported food in dietary scenario analysis. Such a distinction is made only in one of the reviewed articles.

The use to which a piece of land is best suited is affected by a variety of factors, several of which go beyond geographical and ecological considerations. Two important questions in this context are; who owns the land? And what is its current use? Ecological and social consequences of land use change may differ depending on whether a top-down or bottom-up perspective is applied. Today much of the research, as in this thesis, is done with a top-down perspective by which the use and availability of land is analyzed from a national, regional or even global perspective. However, to answer the two previous questions a change of focus is required from a top-down to a bottom- up perspective, which would account for local effects at the place where the land use change is actually taking place.

How the livelihood of the people in developing regions is affected by land use changes is of special concern as it is in these regions (e.g. Africa) the largest potential for increased intensity in agriculture and expanding land in cultivation is estimated to be. Poor people in these areas also often rely more heavily on local ecological resources and surrounding ecosystem services, which makes them particularly vulnerable to food and energy insecurity as a result of changes in land use.

As a top-down perspective may lead to a loss of information of the effects at the local level, while a bottom-up perspective may be unsufficient to understand the dimensions of a problem at a higher level, research from both perspectives is required, as well as research in which land availability and conflicts are analyzed from an integrated top-down and bottom-up perspective.

6.4 Accounting for uncertainty

In this thesis uncertainty assessment has been emphasized. Despite the knowledge of the uncertainty related to LCA data of food and dietary scenario analysis the literature review showed that most articles report the environmental impact of dietary scenarios in precise numbers without any uncertainty or sensitivity assessment, making it difficult to determine the reliability of the results.

According to the ISO standard the interpretation phase in LCA should include an evaluation of the completeness, sensitivity and compliance of the analysis (ISO, 2006b). This is required in order to help the reader to determine which conclusions can be drawn from the results and is critical also in dietary scenario analysis.

To improve the knowledge of how to reduce the environmental impact of food consumption and production, researchers should in the future be better able to analyze, evaluate and report the uncertainty in their methods and results.

6.5 Sustainable eating habits – How to get there?

High priority should be given to measures for promoting more sustainable eating habits, which include eating fewer meat and dairy products, avoiding excessive food intake and reducing food waste (Garnett, 2011). From public health-based interventions it is well known that implementation of changes in diet is difficult and that despite knowing what a healthier diet implies people often find it difficult to change their eating habits (Davies, 2011). Besides increased knowledge of how consumption (and production) of food can be improved, a better understanding of how to implement these changes in the society is thus required in order to increase the sustainability of the food system.

Policies for influencing the sustainability of food systems can be categorized into information-based (e.g. product labels, marketing, education, campaigns), market-based (e.g. subsidies, taxes, fees) and regulatory instruments (e.g. laws, policies, certifications, public procurement) (Reisch, 2011). Information-based instruments are the cheapest and most widely used measure to influence the eating habits of general public. Several countries have also developed national polices or guidelines for sustainable food consumption (e.g. Sweden, Netherlands, UK). However, to meet environmental goals by raising awareness is unlikely to be sufficient solely. It is more likely that a combination of several different interventions will be required (Reisch, 2011, SBA, 2013).

One option under discussion is to impose a tax on climate intensive foods such as meat. To promote a healthier diet, several countries have already implemented such market-based instruments, for example, by using nutrient- and food-based taxes on fat, sugar, salt, “junk food”, sweetened drinks and subsidies for fruits and vegetables (Mytton et al., 2012, Powell et al., 2013). According to Wirsenius et al. (2011) a tax on animal-based food in the EU, equivalent to 60 euros per ton CO_2 eq., could reduce the GHG emissions of current EU agriculture by 7% and release about 11 Mha of permanent pasture and 4 Mha of cropland for other uses. The price elasticity of meat products has previously been estimated to be 0.7-0.8 (Andreyeva et al., 2010), meaning that a 10% increase in price, on average, would reduce consumption by 7-8%.

Which policy instruments that are most effective for a development towards more sustainable food consumption, from a holistic perspective, and how these can be successfully implemented, is an area of research that requires further exploration. In this work, knowledge gained from the area of public health, where experience and a research tradition in this area is well established, may be useful.

6.6 Research requirements - Summary

Below identified areas in need of further research are listed:

- Improved knowledge on how much meat, especially red meat, can be included in a sustainable diet.
- Improved knowledge of the environmental impact of substitutes and complements to meat.
- Further analysis of the future role of processed vegetarian meat substitutes, fortified foods and supplements for increased sustainability in diet.
- Dietary scenario analysis where the scenarios are adapted to different groups of a population, based on current consumption patterns and nutritional requirements.
- Improved knowledge of the effect of dietary change in different geographical regions with different habits, cultures and conditions.
- More research focusing on ways to prevent the development of unhealthy and resource-intensive food habits in developing countries/regions.
- Further analysis on effects of land use of changes in food production and consumption which distinguish between types of agricultural land and specify its geographical location.
- Research in which availability of land and conflicts concerning land use are analyzed by the application of integrated, top-down (global/regional/national) and bottom-up (local) perspectives.
- Improved knowledge on the impact of uncertainty and variability in dietary scenario analysis.
- Improved knowledge of policy instruments for more sustainable food consumption and production and their effectiveness in different regions.
- Improved knowledge of how policy instruments for sustainable food consumption and production can be implemented successfully.
- Holistic inter- and trans-disciplinary assessments of food consumption and production which include more sustainability aspects.

7 Concluding remarks

There is an urgent need for action to reduce environmental pressures from the food sector and improve global health. In this thesis the potential of dietary change as a measure to reduce environmental impact and increase health is analyzed with special attention to uncertainty aspects in the data and methods applied. The findings can be used to improve the performance and interpretation of interdisciplinary, sustainability assessments of food and can contribute to a better understanding of the environmental and health effects of dietary change.

The results illustrate that awareness of the variability and uncertainty in the data and methods used can be crucial for a proper use and interpretation of results in sustainability studies of food and diets. It is further suggested that dietary change, in areas with unrestricted diets, could play an important role in reaching environmental and health goals, with a potential of up to 50% to reduce GHG emissions and land use demand from the diet. The potential to improve the sustainability of the food system through dietary change can be substantial and depends mainly on the amount and type of meat included in the diet.

The meaning of the term ´sustainable meat consumption´ is still under discussion. According to this thesis sustainable meat consumption in a developed country/region perspective, with regard to nutrition, health, climate and land demand is characterized by a large proportion of white meat, limited amounts of red and ruminant meat, avoidance of processed meat and a limitation in total meat intake to about 75 ± 55 grams of cooked meat per day (27± 20 kg per year), depending on the type of meat included in the diet and the sustainability perspective considered.

8 References

Aboelela S W, Larson E, Bakken S, Carrasquillo O, Formicola A, Glied S A, Haas J, Gebbie K M (2007). Defining Interdisciplinary Research: Conclusions from a Critical Review of the Literature. *Health Services Research, 42(1): 329-346.*

Aiking H (2011). Future protein supply. *Trends in Food Science & Technology, 22(2): 112-120.*

Alcamo J (2009). Environmental futures: the practice of environmental scenario analysis. *Elsevier, Amsterdam.*

Amcoff E, Edberg A, Enghardt Barbieri H, Lindroos A K, Nälsen M, Warensjö Lemming E (2012). Riksmaten - vuxna 2010-11. Livsmedels- och näringsintag bland vuxna i Sverige, *(English title:* Food and Nutrient intake among adults in Sweden*). Swedish Food Agency, Uppsala.*

Andreyeva T, Long M W, Brownell K D (2010). The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food. *American Journal of Public Health, 100(2): 216-222.*

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(4): 1046-1055.*

Asgar M A, Fazilah A, Huda N, Bhat R, Karim A A (2010). Nonmeat Protein Alternatives as Meat Extenders and Meat Analogs. *Comprehensive Reviews in Food Science and Food Safety, 9(5): 513-529.*

Aston L M, Smith J N, Powles J W (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).*

Audsley E, Chatterton J, Graves A, Morris J, Murphy-Bokern D, Pearn K, Sandars D, Williams A (2010). Food, land and greenhouse gases. The effect of changes in UK food consumption on land requirements and greenhouse gas emissions. *The Committee on Climate Change.*

Barilla centre for food and nutrition (2012). Double Pyramid: enabling sustainable food choices. *Downloaded from http://www.barillacfn.com/wp-content/uploads/2012/10/pp_dp2012_eng.pdf (accessed 2013-06-26).*

Baumann H, Tillman A-M (2004). The hitch hiker´s guide to LCA. *Studentlitteratur, Lund.*

Berkow S E, Barnard N (2006). Vegetarian diets and weight status. Nutrition Reviews, 64(4): 175-188.

Berners-Lee M, Hoolohan C, Cammack H, Hewitt C N (2012). The relative greenhouse gas impacts of realistic dietary choices. *Energy Policy, 43: 184-190.*

Björklund A (2002). A Survey of approaches to improve reliability in LCA. *International Journal of LCA, 7(2): 64–72.*

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.*

Bruinsma J (2009). The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050? How to feed the World in 2050. *Proceedings of a technical meeting of experts, Rome, Italy, 24-26 June 2009.*

Carlsson-Kanyama A (1998). Climate change and dietary choices - how can emissions of greenhouse gases from food consumption be reduced? *Food Policy, 23 (3-4): 277-293.*

Carlsson-Kanyama A, González A D (2009). Potential contributions of food consumption patterns to climate change. *American Journal of Clinical Nutrition, 89(5): S1704-S1709.*

Cederberg C, Sonesson U, Henriksson M, Sund V, Davis J (2009). Greenhouse gas emissions from Swedish production of meat, milk and eggs 1990 and 2005. *Swedish Institute for Food and Biotechnology, Report No 793. Downloaded from http://www.sik.se/archive/pdf-filer-katalog/sr793 (accessed 2013-01-12).*

Craig W J (2010). Nutrition Concerns and Health Effects of Vegetarian Diets. *Nutrition in Clinical Practice, 25(6): 613-620.*

Davies S (2011). Making sustainable choices easier. *Nutrition Bulletin, 36(4): 454-459.*

Davis J, Sonesson U, Baumgartner D U , Nemecek T (2010). Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. *Food Research International, 43(7): 1874-1884.*

de Vries M, de Boer I J M (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science 128(1-3): 1-11.*

Enghardt Barbieri H, Lindvall C (2003). De svenska näringsrekommendationerna översatta till livsmedel*, (English title:* The Swedish nutritional recommendations translated to foods*). Report No 1/2003, Swedish Food Agency, Uppsala. Downloaded from http://www.slv.se/upload/dokument/rapporter/mat_naring/RapportSNO.pdf (accessed 2013-04-14).*

EC (European Commission) (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.*

EC (European Commission) (2007). Limiting global climate change to 2 degrees Celsius - The way ahead for 2020 and beyond. *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Brussels.*

EC (European Commission) (2010). Agricultural statistics. Main results 2008-09, *Eurostat. Downloaded from http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ED-10-001/EN/KS-ED-10-001-EN.PDF (accessed 2013-08-29).*

EC (European Commission) (2011). A Roadmap for moving to a competitive low carbon economy in 2050 *(COM(2011)) 112 final), Commission staff workining document Impact assessment. Downloaded from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF (accessed 2013-08-29).*

FAO (Food and Agriculture Organization of the United Nations) (2006). Global land use area change matrix. *Forest Resource Assessment, Working Paper 134, FAO, Rome. Downloaded from http://www.fao.org/docrep/010/ag049e/AG049E03.htm (accessed 2013-08-29).*

FAO (Food and Agriculture Organization of the United Nations) (2009). The state of food and agriculture: Livestock in balance. *FAO, Rome. Downloaded from http://www.fao.org/docrep/012/i0680e/i0680e.pdf (accessed 2013-08-29).*

FAO (Food and Agriculture Organization of the United Nations) (2011). Sustainable diet and biodiversity. Directions and solutions for policy, research and action. *FAO, Rome. Downloaded from http://www.fao.org/docrep/016/i3004e/i3004e.pdf (accessed 2013-08-29).*

FAO (Food and Agriculture Organization of the United Nations) (2013). Sustainable food consumption and production. *FAO, Rome. Downloaded from http://www.fao.org/ag/ags/sustainable-food-consumption-and-production/en/ (accessed 2013-06-18).*

FAO STAT (2013). Agriculture statistics for 2009. *FAO, Rome. Downloaded from http://faostat.fao.org (accessed 2013-08-28).*

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

Ferguson L R (2010). Meat and cancer. *Meat Science, 84(2): 308-313.*

Finnagan T (2010a). Food 2030 Life cycle analysis and the role of quorn foods within the new fundamentals of food policy. *Summary document. Downloaded from http://www.mycoprotein.org/assets/timfinniganfood2030.pdf (accessed 2008-08-28).*

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

Fraser G E (2009). Vegetarian diets: what do we know of their effects on common chronic diseases? *(vol 89, pg 1607S, 2009). American Journal of Clinical Nutrition, 90(1): 248-248.*

Friel S, Dangour A D, Garnett T, Lock K, Chalabi Z, Roberts I, Butler A, Butler C D, Waage J, McMichael A J, Haines A (2009). Health and Climate Change 4 Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. *Lancet, 374(9706): 2016-2025.*

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.*

Ge K (2011). The transition of Chinese dietary guidelines and the food guide pagoda. *Asia Pacific Journal of Clinical Nutrition, 20(3): 439-446.*

German Nutrition Society (2008). The Nutrition Report 2008. *Downloaded from http://www.dge.de/pdf/en/DGE-Nutrition-Report-summary-2008.pdf (accessed 2013-08-29).*

Glenn J, Gordon T (eds) (2003). Scenarios. *In: Futures Research Methodology, The Futures Group International, American Council for the UNU, The Millenium Project.*

González A D, Frostell B, Carlsson-Kanyama A (2011). Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation. *Food Policy, 36(5): 562-570.*

Hallström E, Ahlgren S, Börjesson P (2011). Challenges and opportunities for future production of food, feed and biofuel - A land use perspective. *Department of Environmental and Energy Systems Studies, Report No 74, Lund University, Lund. Downloaded from http://miljo.lth.se/personal/elinor_hallstroem/publications/ (accessed 2013-08-28).*

Hallström E, Börjesson P (2013a). Meat-consumption statistics: reliability and discrepancy. *Sustainability: Science, Practice & Policy, 9(2).*

Hallström E, Röös E, Börjesson P (2013b). Sustainable meat consumption: a quantitative analysis of nutritional intake, climate impact and land use. *Submitted.*

Huijbregts M (2002). Uncertainty and variability in environmental life-cycle assessment. *The International Journal of Life Cycle Assessment, 7(3): 173-173.*

Hunt R G, Franklin W E, Welch R O, Cross J A, Woodall A E (1974). Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives. *EPA*

Report 530/SW-91c, United States Environmental Protection Agency, Office of Solid Waste Management Programs, Washington DC.
Huppes G, Curran A M (2012). Environmental Life Cycle Assessment: Background and Perspectives. *In: Curran, M A (ed.), Life Cycle Assessment Handbook. A guide for environmentally sustainable products, Wiley, Ney Jersey.*
IEA (International Energy Agency) (2013). World Energy Outlook. *OECD/IEA. Downloaded from http://www.worldenergyoutlook.org/publications/ (accessed 2013-08-28).*
IPCC (Interngovernmental Panel on Climate Change) (2007). IPPC Fourth Assesment Report: Climate Change 2007. *Synthesis Report. Contribution to Working groups I, II and III to the Fourth Assessment Report of the Interngovernmental Panel on Climate Change, Pachauri R K, Reisinger A (eds.), IPCC, Geneva.*
ISO (International Organisation for Standardisation) (2006a). Environmental management. Life cycle assessment - Principles and framework. *ISO 14040, ISO, Geneva.*
ISO (International Organisation for Standardisation) (2006b). Environmental management. Life cycle assessment - Requirements and guidelines. *ISO 14044, ISO, Geneva.*
Jungbluth N, Tietje O, Scholz R W (2000). Food purchases: impacts from the consumers' point of view investigated with a modular LCA. *The International Journal of Life Cycle Assessment, 5(3): 134-142.*
Kahn H, Weiner A J (1968). The Year 2000: a Framework for Speculation on the Next Thirty-three Years. *Collier Macmillan, New York.*
La Sociedad Española de Nutrición Comunitaria, La Sociedad Española de Medicina de Familia y Comunitaria (2007). Consejos para una alimentacion saludable. *Downloaded from http://www.semfyc.es/pfw_files/cma/Informacion/modulo/documentos/guia_alimentacion.pdf(accessed 2011-06-20).*
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 Assessment in the Agri-Food Sector, 22-24 Sep 2010, Bari.*
Li D (2011). Chemistry behind Vegetarianism. *Journal of Agricultural and Food Chemistry, 59(3): 777-784.*
Macdiarmid J I, Kyle J, Horgan G W, 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? *American Journal of Clinical Nutrition, 96(3): 632-639.*
Macdiarmid J I (2013). Is a healthy diet an environmentally sustainable diet? *Proceedings of the Nutrition Society, 1(1): 1-8.*

Malthus T R (1798). An Essay on the Principle of Population. *Library of Economics and Liberty, London.*

Meadows D H, Meadows D L, Randers J, Behrens W W (1974). The limits to Growth: a report for the club of Rome´s project on the predicament of mankind. *Universe Books, New York.*

Meier T, Christen O (2012). Environmental impacts of dietary recommendations and dietary styles: Germany as an example. *Environmental Science & Technology, 47(2): 877-888.*

Micha R, Wallace S K, Mozaffarian D (2010). Red and Processed Meat Consumption and Risk of Incident Coronary Heart Disease, Stroke, and Diabetes Mellitus A Systematic Review and Meta-Analysis. *Circulation, 121(21): 2271-U52.*

Miles L (2008). The new WCRF/AICR report - food, nutrition, physical activity and the prevention of cancer: a global perspective. *Nutrition Bulletin, 33(1): 26-32.*

Millward D J, Garnett T (2010). Food and the planet: nutritional dilemmas of greenhouse gas emission reductions through reduced intakes of meat and dairy foods. *Proceedings of the Nutrition Society, 69(1): 103-118.*

Mytton O T, Clarke D, Rayner M (2012). Taxing unhealthy food and drinks to improve health. *BMJ, 344.*

Nakicenovic N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, Grübler A, Yong-Jung T, Kram T, Lebre-La Rovere E, Michaelis L, Mori S, Morita T, Pepper W, Pitcher H, Price L, Riahi K, Roehrl A, Rogner H, Sankovski A, Schlesinger M, Shukla P, Smith S, Swart R, van Rooijen S, Victor N, Dadi Z (2000). Emission Scenarios. *Nakicenovic, N, Swart, R (eds.) IPCC, Cambridge University Press, Cambridge.*

National Academy of Sciences, National Academy of Engineering, Insitute of Medecine (2005). Facilitating Interdisciplinary Research, *The National Academic Press. Washington D.C.*

NIN (National Institute of Nutrition) (2010). Dietary guidelines for indians - A manual. *Downloaded from http://www.ninindia.org/DietaryguidelinesforIndians-Finaldraft.pdf (accessed 2013-08-28).*

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(6): 760-770.*

Nonhebel S, Raats J (2007). Environmental impact of meat substitutes: Comparison between quorn and pork. *In Proceedings from the 5th international conference LCA in Foods, 25–26 April, Gothenburg.*

NCM (Nordic Council of Ministers) (2004). Nordic Nutrition Recommendations 2004. *Norden, Copenhagen.*

Popp A, Lotze-Campen H, Bodirsky B (2010). Food consumption, diet shifts and associated non-CO2 greenhouse gases from agricultural production. *Global Environmental Change, 20(3): 451-462.*

Powell T W R, Lenton T M (2012). Future carbon dioxide removal via biomass energy constrained by agricultural efficiency and dietary trends. *Energy & Environmental Science, 5(8): 8116-8133.*

Powell L, Chriqui J, Khan T, Wada R, Chaloupka F (2013). Assessing the potential effectiveness of food and beverage taxes and subsidies for improving public health: a systematic review of prices, demand and body weight outcomes. *Obesity Reviews, 14(2): 110-128.*

Refsgaard J C, van der Sluijs J P, Højberg A L, Vanrolleghem P A (2007). Uncertainty in the environmental modelling process–a framework and guidance. *Environmental modelling & software, 22(11): 1543-1556.*

Reijnders L, Soret S (2003). Quantification of the environmental impact of different dietary protein choices. *American Journal of Clinical Nutrition, 78(3): 664S-668S.*

Reilly M, Willenbockel D (2010). Managing uncertainty: a review of food system scenario analysis and modelling. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554): 3049-3063.*

Reisch L, Lorek S, Biet S (2011). Policy Instrument for Sustainable FoodConsumption *CORPUS Discussion Paper 2, CORPUS, Brussels. Downloaded from http://www.scp- knowledge.eu/sites/default/files/Reisch%20et%20al%202011%20 Sustainable%20Food%20-%20Policies.pdf (accessed 2013-08-28).*

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. *Progress in Industrial Ecology, an International Journal, 6(4): 340-354.*

Risku-Norja H (2011). From environmental concernt towards sustainable food provisioning. Material flow and food consumption scenario studies on sustainability of agri-food systems. *Doctoral thesis, Univeristy of Helsinki, Helsinki.*

Rockstrom J, Steffen W, Noone K, Persson A, Chapin F S, Lambin E, Lenton T M, Scheffer M, Folke C, Schellnhuber H J, Nykvist B, de Wit C A, Hughes T, van der Leeuw S, Rodhe H, Sorlin S, Snyder P K, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell R W, Fabry V J, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P , Foley J (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society, 14(2).*

Rothman D S (2008). Chapter Three A Survey of Environmental Scenarios. *In: Joseph, A (ed.), Developments in Integrated Environmental Assessment, Elsevier, Amsterdam.*

Rubinstein R, Kroese D (2007). Simulation and the Monte Carlo method. *Wiley-Interscience, New Jersey.*

Röös, E (2013a). Analysing the carbon Footprint of Food. Insigths for Consumer Communication. *Doctoral thesis. Swedish University of Agricultural Sciences.*

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

Röös E (2013c). Köttguiden *(English title:* The meat guide*). Swedish University of Agriculture. Downloaded from http://www.kottguiden.se/faq.html#mangd (accessed 2013-06-27).*

Sadler M J (2004). Meat alternatives - market developments and health benefits. *Trends in Food Science & Technology, 15(5): 250-260.*

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(2): 249-262.*

SBA (Swedish Board of Agriculture) (2011). Consumption of food and nutritive values, data up to 2009. *Report no 2011:2. Downloaded from http://www.sjv.se/webdav/files/SJV/Amnesomraden/Statistik,%20fakta/Livsmedel/Statistikrapport2011_2/20112.pdf (accessed 2013-02-07).*

SBA (Swedish Board of Agriculture) (2013). Hållbar köttkonsumtion. Vad är det? Hur når vi dit? *(English title:* Sustainable meat consumption. What is it? How do we reach it?*). Report no 2013:1. Downloaded from http://www.jordbruksverket.se/download/18.5df17f1c13c13e5bc4f800039403/En+h%C3%A5llbar+k%C3%B6ttkonsumtion.pdf (accessed 2013-08-30).*

Scarborough P, Allender S, Clarke D, Wickramasinghe K, Rayner M (2012). Modelling the health impact of environmentally sustainable dietary scenarios in the UK. *European Journal of Clinical Nutrition, 66(6): 710-715.*

Schakel S F, Buzzard I M , Gebhardt S E (1997). Procedures for Estimating Nutrient Values for Food Composition Databases. *Journal of Food Composition and Analysis, Vol. 10, pp 102-114.*

Schakel S F (2001). Maintaining a Nutrient Database in a Changing Marketplace: Keeping Pace with Changing Food Products—A Research Perspective. *Journal of Food Composition and Analysis, Vol. 14, pp 315-322.*

Schau E M, Fet A M (2008). LCA studies of food products as background for environmental product declarations. *International Journal of Life Cycle Assessment, 13(3): 255-264.*

SEPA (Swedish Environmental Protection Agency) (2013). Miljömålen *(English title:* The environmental goals*). Downloaded from http://www.miljomal.se/ (accessed 2013-08-28).*

SEPA (Swedish Environmental Protection Agency) (2012). Underlag till en svensk färdplan för ett Sverige utan klimatutsläpp 2050. *(English title:* Material for a Swedish roadmap for a Sweden without Climate impact in 2050*). Report no 6487. Downloaded from http://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6487-7.pdf (accessed 2013-08-30).*

SEPA (Swedish Environmental Protection Agency) (2008). Konsumtionens klimatpåverkan. *(English title:* Climate impact from consumption*). Report no 5903. Downloaded from http://www.naturvardsverket.se/Documents/publikationer/978-91-620-5903-3.pdf (accessed 2013-08-30).*

*SFA (Swedish Food Agency) (2012).*Vägningstal för kött (data från 1993) *(English title:* weight data for meat (data from 1993). *SFA, Uppsala.*

SFA (Swedish Food Agency) (2013). Om livsmedelsdatabasen *(English title:* About the food database*). Downloaded from http://www.slv.se/sv/grupp1/Mat-och-naring/Vad-innehaller-maten/Om-livsmedelsdatabasen/ (accessed 2013-09-15).*

Sinha R, Cross A J, Graubard B I, Leitzmann M F, Schatzkin A (2009). Meat Intake and Mortality A Prospective Study of Over Half a Million People. *Archives of Internal Medicine, 169(6): 562-571.*

Sonesson U, Davis J, Ziegler F (2010). Food Production and Emissions of Greenhouse Gases. An overview of the climate impact of different product groups. *Swedish Institute for Food and Biotechnology, Report No 802. Downloaded from http://www.sik.se/archive/pdf-filer-katalog/SR802.pdf (accessed 2012-08-04).*

Srinivasan C S, Irz X, Shankar B (2006). An assessment of the potential consumption impacts of WHO dietary norms in OECD countries. *Food Policy, 31(1): 53-77.*

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(1-2): 83-102.*

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, Haan C de (2006). Livestock's long shadow: environmental issues and options. *Renewable Resources Journal, 24(4): 15-17.*

Swart R J, Raskin P, Robinson J (2004). The problem of the future: sustainability science and scenario analysis. *Global Environmental Change, 14: 137-147.*

SPMA (Swedish Poultry Meat Association) (2012). Estimated Swedish sales of bone-free chicken. *Conversation with Maria Donis (Stockholm), Jimmy Samuelsson (Mörbylånga), 2012-06-06.*

Temme E H, van der Voet H, Thissen J T, 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. *Public Health Nutrition, doi:10.1017/S1368980013000232: 1-8.*

Tukker A, Goldbohm R A, de Koning A, Verheijden M, Kleijn R, Wolf O, Perez-Dominguez I, Rueda-Cantuche J M (2011). Environmental impacts of changes to healthier diets in Europe. *Ecological Economics, 70(10): 1776-1788.*

USDA, HHS (U.S. Department of Agriculture and U.S. Department of Health and Human Services) (2010). Dietary Guidelines for Americans*, 2010. 7th Edition. Washington DC. Downloaded from http://www.cnpp.usda.gov/dietaryguidelines.htm (accessed 2013-08-30).*

UNEP (United Nations Environment Programme) (2002). Global Environmental Outlook 3: Past, Present, and Future Perspectives. *Earthscan Publications. London. Downloaded from http://www.unep.org/geo/geo3.asp (accessed 2013-08-30).*

UNEP (United Nations Environment Programme) (2010). The Emissions Gap Report: Are the Copenhagen Accord Pledges Sufficient to Limit Global Arming to 2 degrees or 1.5 degrees? A preliminary assessment. *Downloaded from http://www.unep.org/publications/ebooks/emissionsgapreport/pdfs/The_EMISSIONS_GAP_REPORT.pdf (accessed 2013-08-30).*

UNEP (United Nations Environment Programme) (2013). IEA Training Manual - Model 6. Developing scenarios - A complete process. *Downloaded from http://www.unep.org/ieacp/iea/training/manual/module6/1253.aspx (accessed 2013-05-31).*

UN (United Nations) (2010). World Population Prospects: The 2010 Revision. *Department of Economic and Social Affairs. Downloaded from http://esa.un.org/unpd/wpp/Documentation/WPP%202010%20publications.htm. (accessed 2013-07-13).*

Wallen A, Brandt N, Wennersten R (2004). Does the Swedish consumer's choice of food influence greenhouse gas emissions? *Environmental Science & Policy, 7(6): 525-535.*

Walter P, Infanger E, Muhlemann P (2007). Food pyramid of the Swiss Society for Nutrition. *Annals of Nutrition and Metabolism, 51: 15-20.*

Van Duyn M A S, Pivonka E (2000). Overview of the Health Benefits of Fruit and Vegetable Consumption for the Dietetics Professional: Selected Literature. *Journal of the American Dietetic Association, 100(12): 1511-1521.*

WCED (World Commission on Environment and Development) (1987). Our Common Future. *Oxford University Press, New York.*

Weieidema B, Wesnaes M, Hermansen J, Kristensen T, Halberg N (2008). Environmental Improvment Potential of Meat and Dairy Products. *EUR 23491 EN – 2008. European Commission Joint Research Centre. Downloaded from*

http://ftp.jrc.es/EURdoc/JRC46650.pdf (accessed 2013-01-11).
Westrich B J, Buzzard I M, Gatewood L C , McGovern P G (1994). Accuracy and Efficiency of Estimating Nutrient Values in Commercial Food Products Using Mathematical Optimization. *Journal of Food Composition and Analysis, Vol. 7, pp 223-239. WHO (World Health Organization) (1948).* WHO definition of health. *Downloaded from http://www.who.int/about/definition/en/print.html (accessed 2013-06-17).*
WHO (World Health Organization (2002). Protein and amino acid requirements in human nutrition: report of a joint FAO/FAO/UNO expert consultation. *WHO Technical Report Series 935. WHO, Geneva.*
WHO (World Health Organization) (2011). Obesity and overweight. *Downloaded from http://www.who.int/mediacentre/factsheets/fs311/en/index.html (accessed 2011-07-05).*
WHO/FAO (World Health Organization/Food and Agriculture Organization of the United Nations) (2003). Diet, nutrition, and the prevention of chronic disease. *Report of 164 a joint WHO/FAO Expert Consultation. Geneva. Downloaded from http://whqlibdoc.who.int/trs/WHO_TRS_916.pdf (accessed 2013-01-10).*
Vieux F, Darmon N, Touazi D, Soler L G (2012). Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? *Ecological Economics, 75: 91-101.*
Willet W. S, L. (2013). Foods and nutrients. *In: Willet, W (ed.) Nutritional Epidemiology. Oxford, New York: Oxford Univeristy Press,.*
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? *Agricultural Systems, 103(9): 621-638.*
Wirsenius S, Hedenus F, Mohlin K (2011). Greenhouse gas taxes on animal food products: rationale, tax scheme and climate mitigation effects. *Climatic Change, 108(1-2): 159-184.*
WCRF/AICR (World Cancer Research Fund/American Institute for Cancer Research) (2007). Food, Nutrition, Physical Activity, and the Prevention of Cancer: a Global Perspective. *Washington DC.*
WFP (World Food Programe) (2013). Hunger. *Downloaded from http://www.wfp.org/hunger (accessed 2013-06-26).*
Wyness L, Weichselbaum E, O'Connor A, Williams E B, Benelam B, Riley H, Stanner S (2011). Red meat in the diet: an update. *Nutrition Bulletin, 36(1): 34-77.*
Xueqin Z, van Ierland E (2004). Protein Chains and Environmental Pressures: A Comparison of Pork and Novel Protein Foods. *Environmental Sciences, 1(3): 254-276.*

Appendix Dietary scenarios

Table VI. Effect on GHG emissions on dietary change

REFERENCE, description	SCENARIO	GHG emissions (tCO_2 eq./person per year)	Change compared to reference scenario
(Saxe et al., 2013) Cradle-retail	Ref: Average Danish diet	2.0	
	Healthy diet according to NNR[1]	1.9	-7%
	Healthy and local diet according to OPUS[2]	1.8	-12%
	Healthy, local and organic diet according to OPUS[2]	1.9	-5%
	Healthy, local and organic diet according to OPUS[2], red meat partially replaced by chicken[3]	1.8	-14%
	Healthy, local and organic diet according to OPUS[2], red meat partially replaced by chicken[4]	1.7	-19%
	Healthy and local diet according to OPUS[2], red meat partially replaced by chicken[4]	1.5	-26%
	Lacto-ovo vegetarian and local diet	1.5	-27%
(Meier and Christen, 2012) Cradle-retail	Ref: Average German diet in 2006	2.1	

	Healthy diet according to D-A-C-H[5]	1.8	-11%
	Healthy diet according to UGB[6]	1.8	-12%
	Lacto-ovo vegetarian	1.6	-24%
	Vegan	1.0	-53%
(Berners-Lee et al., 2012) Cradle-retail	Ref: Average UK diet in 2009	2.7	
	Vegetarian diet, meat replaced by dairy products	2.1	-22%
	Self-reported vegetarian diet[7]	2.2	-18%
	Healthy vegetarian diet[8]	2.0	-25%
	Vegan diet, no health considerations	1.9	-31%
	Self-reported vegan diet[8]	2.1	-23%
	Healthy vegan diet	2.0	-25%
(Vieux et al., 2012) Cradle-retail	Ref: Average French diet in 2006-2007	1.5	
	Balancing energy intake and expenditure, assuming low physical activity	1.3	-11%
	Balancing energy intake and expenditure, assuming moderate physical activity	1.5	-2%
	20% of meat intake (min 50g meat) replaced by self-selected[9] fruit and vegetables	1.5	0%

	20% of meat intake (min 50g meat) replaced by self-selected[9] milk and dairy products	1.5	-2%
	20% of meat intake (min 50g meat) replaced by self-selected[9] mixed foods	1.5	-3%
	Reduced meat intake to 50g/d and removal of deli meat replaced by self-selected[9] fruit and vegetables	1.5	+3%
	Reduced meat intake to 50g/d and removal of deli meat replaced by self-selected[9] milk and dairy	1.4	-4%
	Reduced meat intake to 50g/d and removal of deli meat replaced by self-selected[9] mixed foods	1.4	-7%
(Macdiarmid et al., 2012) Cradle-farm gate	Ref: Average UK diet of women in 1990	1.4	
	Healthy and sustainable diet[10]	0.9	-36%
(Aston et al., 2012) Cradle-retail	Ref: Average UK diet in 2000/2001	1.4	
	Doubled proportion of vegetarians, low consumption of red and processed meat in remaining population[11]	1.3	-12%
(Tukker et al., 2011) Cradle-retail	Ref: Average diet in five EU27 regions in 2003	2.6	

	Healthy diet based on European dietary guidelines[12]	2.6	0%
	Healthy diet with less than 300g red meat per week and avoidance of processed meat	2.4	-7%
	Mediterranean diet with reduced intake of red meat	2.4	-6%
(Fazeni and Steinmüller, 2011) Cradle-farm gate	Ref: Average Austrian diet in 2001-2006	0.9	
	Healthy diet[13]	0.6	-32%
	Healthy[13] and local[14] diet	0.6	-35%
(Audsley et al., 2010) Cradle-farm gate	Ref: Average UK diet in 2005	1.3	
	50% of meat and dairy replaced by plant-based food	1.0	-19%
	75% of ruminant meat replaced by pig and poultry	1.2	-9%
	50% of pig and poultry replaced by plant-based food	1.2	-3%
(Risku-Norja et al., 2009) Cradle-farm gate	Ref: Average Finnish diet	1.7	
	Healthy diet[15]	1.4	-16%
	No dairy products, ruminant meat replaced by pork and poultry	1.1	-33%
	Vegan diet	0.9	-48%

REFERENCE, description	FUTURE SCENARIO	GHG emissions ($MtCO_2$ eq/year)	Change compared to reference scenario
(Popp et al., 2010) Global scenario, cradle-farm gate, Non GHG emissions only	Ref: Average regional diets in 2055 kept at 1995 levels. Cropland expansion of 3.5% per decade between 1995 and 2055.	8700	
	Increased energy intake and share of livestock products[16]	15000	+76%
	Increased energy intake, reduced share of livestock products[17]	4300	-51%
	Increased energy intake and share of livestock products[16], technical mitigation in agriculture	9800	+13%
	Increased energy intake, reduced share of livestock products[17], technical mitigation in agriculture	2500	-71%

[1]Healthy diet according to Nordic Nutrition Recommendations. [2]Nordic diet containing locally produced foods of which 75% is organically produced. Meat is partially replaced with fruit and vegetables. [3]Average intake of chicken, beef and other types of meat is multiplied by the factors 2.0, 0.5 and 0.67, respectively. [4]Average intake of chicken, beef and other types of meat is multiplied by the factors 3.0, 0.2 and 0.2, respectively. [5]Official dietary recommendations of the German Nutrition Society. [6]Dietary recommendations by the Federation for Independent Health Consultation. [7]Self-selected diets based on food choices of American vegetarians and vegans. [8]Meat is replaced by plant-based food categories considered to be healthy (e.g. pastas, rice, pulses, cereals, breads, salads, vegetables, fruit, nuts, seeds), dairy consumption remains unchanged. [9]Self-selected diets based on food choices of a sample of adults living in France. [10]Diet fulfilled nutrient requirement of fertile women, contained 190 g of cooked red meat per week and 555 g fruit and vegetables per day, and was created to minimize food waste and greenhouse gas emissions. [11]Consumption of red and processed meat adapted to the dietary pattern of the lowest fifth of population. Average intake of red and processed meat reduced from 91 to 52 g/d in men and 54 to 30 g/d in women. [12]Dietary recommendations based on Health Council of the Netherlands and the WHO/FAO. [13]Based on DGE recommendations including reduced meat intake (-60%, all meat types decrease to the same extent), increased intake of fruit, vegetables and cereals and reduced intake of fish and sugar. [14]Food consumption is based on Austrian agriculture production. [15]Based on national health impact dietary recommendations, including increased share of plant based food, reduced share of animal based food and 60% share of present milk consumption. [16]The energy intake and share of livestock products are given by a regression model which links food consumption against predicted GDP. [17]Livestock products share of energy intake decrease by 25% per decade between 1995 and 2055.

Table VII. Effect on land use of dietary change

REFERENCE, description	SCENARIO	Total land use demand (m^2/person, year)	Change compared to reference scenario	Pasture land	Arable/ cropland
(Temme et al., 2013)	Ref: Average Dutch diet of young women in 2003	1400			
	30% of dairy and meat replaced by plant-based food	1100	-16%	-	-
	Vegan diet	700	-51%	-	-
(Meier and Christen, 2012)	Ref: Average German diet in 2006	2100			
	Healthy diet according to D-A-C-H[1]	1800	-15%	-	-
	Healthy diet according to UGB[2]	1700	-17%	-	-
	Lacto-ovo vegetarian	1500	-27%	-	-
	Vegan	1100	-50%	-	-
(Audsley et al., 2010)	Ref: Average UK diet in 2005	3300		2100	1200
	50% of meat and dairy replaced by plant-based food	1900	-42%	800	1200
	75% of ruminant meat replaced by pig and poultry	2000	-39%	700	1300

	50% of pig and poultry replaced by plant-based food	3200	-4%	2100	1100
(Arnoult et al., 2010)	Ref: Average UK diet in 2003-2004	1700		1100	700
	Healthy diet[3]	1500	-17%	800	700
(Risku Norja, 2008)	Ref: Average Finnish diet in 2002, conventional production	3300			
	Healthy diet[4], local conventional production	2600	-21%	-	-
	Mixed diet with no pork and poultry, limited beef intake[5], local conventional production	1900	-42%	-	-
	Vegetarian diet, local conventional production	1700	-48%	-	-
	Average Finnish diet in 2002, local organic production	4900	+48%	-	-
	Healthy diet[4], local organic production	3700	+12%	-	-
	Mixed diet with no pork and poultry, limited	2700	-18%	-	-

	beef intake[5], local organic production				
	Vegetarian diet, local organic production	3100	-6%	-	-

REFERENCE, description	FUTURE SCENARIO	Total land use (Mha, year)	Land use change compared to reference scenario	Pasture land (Mha)	Arable land (Mha)
(Powell and Lenton, 2012), Global scenario	Ref: dietary scenarios in 2050 based on FAO projections	4900		-	-
	High[6] meat consumption, low[7] agricultural efficiency	8800	+81%	-	-
	High[6] meat consumption, high[8] agricultural efficiency	4800	-1%	-	-
	Low[9] meat consumption, high[8] agricultural efficiency	4100	-15%	-	-
	Low[9] meat consumption, low[7] agricultural efficiency	7300	+50%	-	-
(Wirsenius et al., 2010) Global scenario	Ref: dietary scenario for 2030 based on FAO predictions	5300		3600	1700

	A. Increased livestock productivity	4800	-10%	3100	1700
	B. A+ 20% of ruminant meat replaced by pork and poultry	4400	-19%	2700	1700
	C. B+ up to 25% of meat intake is replaced by plant based food, 15-20% reduction of food waste	4200	-22%	2600	1600
(Stehfest et al., 2009) Global scenario	Ref: global average diet in 2050 according to FAO projections	5000		3200	1800
	Ruminant meat replaced by plant-based proteins	2200	-57%	500	1700
	Vegetarian diet	2100	-58%	500	1600
	Vegan diet	1600	-68%	0	1600
	Healthy diet[10]	3500	-30%	1900	1600

[1]Official dietary recommendations of the German Nutrition Society. [2]Dietary recommendations by the Federation for Independent Health Consultation with less meat and more legumes and vegetables. [3]Based on national and international dietary recommendations including reduced consumption of dairy, red meat and sugar and increased intake of fish, fruit, vegetables and cereals.[4]Based on national standard dietary recommendations. [5] Beef consumption is limited to be a by-product from milk production. [6]Average per capita annual meat consumption is expected to rise from 16.06% to 18.8% of daily caloric intake between 2000 and 2050. [7]Efficiency in livestock production and balance between grazing and fodder feeding animals remains at the level in 2000, Yields of vegetal products increase at current rate of 1% per year. [8]Increased efficiency in livestock production, shift from grazing animal production towards pig and poultry production, 20% reduction in food waste between 2000 and 2050. [9]Average per capita annual meat consumption is expected to decrease from 16.06% to 15% of daily caloric intake between 2000 and 2050. [10]Based on recommendations from Harvard Medical school.